EXPRESS MAIL NO. EK102725495US

MACROAGGREGATED PROTEIN CONJUGATES AS ORAL GENETIC IMMUNIZATION DELIVERY AGENTS

[0001] This application claims the benefit of U.S. Provisional Application No. 60/195,680 filed on April 7, 2000.

[0002] The work herein was supported by grants from the United States Government. The United States Government may have certain rights in the invention

FIELD OF INVENTION

[0003] This invention relates to the use of aggregated protein-polycationic polymer conjugates in genetic vaccines. More particularly it relates to the use of macroaggregated albumin conjugates for oral delivery of vaccines.

BACKGROUND OF THE INVENTION

[0004] The mucosal immune system is extremely important in human resistance to microbial pathogens, but complicating the picture is the role of the mucosal immune system in suppressing undesirable antigenic responses to inhaled and ingested antigens in order to avoid massive allergic sensitivity (Mowat, 1987). In addition, systemic immunization usually does not elicit significant mucosal immune responses (Mestecky *et al.*, 1994). In the context of HIV, the genital surface is the most important target tissue for immunity, and it is particularly difficult to immunize directly, especially in the male. Hence, an HIV vaccine aimed at inducing mucosal immunity will almost certainly have to be administered elsewhere (*e.g.*, the gut), but it must still result in the accumulation of immune effector cells and molecules in the genital mucosa. Airway immunization (*e.g.*, intranasal and intratracheal) and gut immunization have both been shown to produce responses with effector cells spilling over to other mucosal surfaces, especially the genital tract. Recent work has revealed that antigens (and particles) are delivered across the mucosal surface relatively unchanged to antigen presenting cells underneath the surface via specialized cells (membranous cells or M cells) that are derived from the normal epithelium. It is generally believed that antigens taken up by the M cells, which cover the mucosal inductive sites, are channeled to parenchymal macrophages, dendritic cells, B lymphocytes and even mast cells. Under some conditions, such as viral infection, or perhaps genetic immunization, the antigen can be processed and perhaps presented directly by the epithelial cells to the underlying B and T cells. Hence, regardless of how the antigen is administered, antigen (or antigen expressed via plasmid DNA) that can be delivered to these antigen presenting cells should result in mucosal immune responses.

[0005] In genetic immunization, a simple mammalian expression plasmid containing the gene for an antigen is administered to the animal rather than the antigen itself. Expression of the antigen gene in this manner produces the antigen intracellularly,

making it a substrate for major histocompatibility (MHC) class I presentation (Schirmbeck *et al.*, 1995) thereby enabling strong cellular immune responses to be produced. The mechanisms of antigen presentation include transfection and expression of the antigen within professional antigen presenting cells (*e.g.*, macrophages or dendritic cells), or transfer of peptides from a different expressing cell (*e.g.*, cytoplasm transfer from muscle cells) to a professional antigen presenting cell (Doe *et al.*, 1996, Huang *et al.*, 1994). Anti-HIV envelope cytotoxic T-lymphocytes (CTL) have been induced in mice and nonhuman primates by genetic immunization (Wang *et al.*, 1994). Furthermore, intramuscular genetic vaccination with influenza nucleoprotein expressing plasmids has produced long-lived $CD8^+$ CTL mediating cross-strain protection against flu (Ulmer *et al.*, 1994). Humoral responses, *e.g.*, to HIV-1 envelope protein (Wang *et al.*, 1993, Lu *et al.*, 1995), are also produced by such immunizations, either by the target cells themselves acting as antigen presenting cells, or by shedding of the protein products from the cell surface and subsequent processing of the peptides by professional antigen presenting cells through the MHC class II pathway. In fact, repeated intramuscular injections of plasmids have resulted in a conversion of the dominant CTL response into a humoral response, with waning of the cellular cytotoxicity response in some reports (Fuller *et al.*, 1994). Hence, the appropriate dose, timing, and route(s) for administration are critical to producing an optimal genetic immunization response.

[0006] Inefficient DNA delivery remains one of the main impediments to successful gene therapy and DNA immunizations (Thierry *et al.*, 1997). Transfection *in vivo* has been accomplished using cationic lipid/DNA complexes administered by injection intravenously (Zhu *et al.*, 1993) and intramuscularly (Mitchell *et al.*, 1995), and by application to mucosal surfaces (Schmid *et al.*, 1994). Naked DNA has also been used intravenously, but it has a very brief half-life (Lew *et al.*, 1995 and Kawabata, et al. 1995) and thus is extremely inefficient. However, intramuscular and intradermal injection of naked DNA has been effective in a variety of animal models. Viral vectors can be very efficient transiently, but the induction of antiviral immune responses prevents repeated administrations and may result in lowered transgene expression (Weichselbaum *et al.*, 1997). In addition, toxicity may result from either cationic lipids or viral vectors in some cases. Microencapsulated plasmids containing reporter genes given orally penetrate the gastrointestinal tract surfaces and cause expression of the foreign genes in the cells of the gut and associated lymphoid tissue (Mathiowitz *et al.*, 1997). Microspheres can also penetrate lymphoid tissue given by other routes as well, as has been observed in studies of protein antigen delivery (Marx *et al.*, 1993 and Jenkins *et al.*, 1995). Delivery of DNA to cutaneous tissues using a gene gun (Williams *et al.*, 1991) has produced humoral systemic immunization (Tang *et al.*, 1992) and cellular responses that were protective in the lung against *Mycoplasma pulmonis* infection (Barry *et al.*, 1995). Despite all of these

different, methods, none has proved to be broadly efficient in gene transfection application *in vivo*.

[0007] Mucosal immunity has been induced by nasal administration of plasmid DNA expression vectors, *e.g.*, protective immunity to flu virus challenge with a vector encoding the influenza hemagglutinin protein (Fynan *et al.*, 1993). Packaging with viral vectors (*e.g.*, adeno-associated viruses), or incorporating antigenic genes into vaccinia virus has been frequently used, but has the disadvantage of inducing an immune reaction to the associated viral proteins as well, limiting the potential for boosting, or for administration of other antigens by the same route.

[0008] Expression library immunization (ELI) is a novel vaccine approach that weds the power of recombinant DNA technology to genetic immunization (Barry *et al.*, 1995). In ELI, a pathogen's genome is broken into small fragments and cloned into mammalian expression plasmids to create a vaccine representing all or most of the antigens of the pathogen. The expression plasmids contain a strong promoter (*e.g.*, CMV) and expression of the protein products can be controlled by fusion to targeting sequences, *i.e.*, the carboxy terminus of ubiquitin, which directs the protein to the proteasome for MHC class I presentation, a signal sequence for secretion, which directs the product to be secreted for antibody induction for MHC class II presentation, or without an additional sequence, which the protein is processed based on the native properties of the protein sequence. ELI was first demonstrated effective against the bacterial pathogen *Mycoplasma pulmonis* by Michael Barry and colleagues (Barry *et al.*, 1995). Expression libraries were generated by fusing fragments of *M. pulmonis* genomic DNA to the carboxy-termini of human growth hormone (containing a signal sequence for secretion) or ubiquitin. Ubiquitin fusions were recently reported to produce CTL, but reduce antibody induction (Gillanders *et al.*, 1997); however, gene gun vaccination with these ELI vaccines for *M. pulmonis* produced both CTL and antibody protection against mycoplasma infection at least an order of magnitude better than the best traditional mycoplasma vaccine available. ELI appears useful for generating multiple immune responses simultaneously, in a manner analogous to that of a live/attenuated pathogen vaccine. Given the pattern of responses seen in the resistant sexually exposed individuals in HIV infections, the broad range of antigen specificities that can be delivered by the expression library approach is particularly attractive. ELI vaccines are also safer than live-attenuated vaccines, because the genome of the pathogen is fragmented and scattered across large numbers of separate plasmids precluding reassembly of a pathogenic viral genome.

[0009] This invention demonstrates for the first time the use of an oral delivery system for a genetic vaccine in which the DNA is conjugated to an aggregated protein and a polycationic polymer. It is noteworthy that although the prior art in genetic vaccines

have utilized other modes of delivery, the strategy of using oral delivery for a DNA vaccine has not been developed, suggesting that this invention is indeed nonobvious.

SUMMARY OF THE INVENTION

[0010] An embodiment of the present invention is a composition comprising an expression vector bound to an aggregated protein-polycationic polymer conjugate, wherein the expression vector comprises a promoter polynucleotide sequence operatively linked to a polynucleotide sequence encoding an antigen .

[0011] In a specific embodiment of the present invention, the polynucleotide sequence encoding the antigen is a fragment of a genome or gene selected from the group of genomes or genes associated with a disease consisting of infectious disease, cancer and autoimmune disease.

[0012] In another specific embodiment of the present invention, the polynucleotide sequence encoding the antigen is a fragment of a genome or gene selected from the group of pathogenic genomes consisting of virus, bacterium, fungus and protozoa. In specific embodiments, the polynucleotide sequence encoding the antigen is a fragment of a genome selected from the group viral genomes consisting of human immunodeficiency virus (HIV), herpes simplex virus (HSV) hepatitis C virus (HCV), influenza virus and respiratory syncytial virus (RSV).

[0013] In a specific embodiment of the present invention, the polynucleotide sequence encoding the antigen is a fragment of a gene selected from the group of genes associated with an autoimmune disease consisting of rheumatoid arthritis, vaculitis, and multiple sclerosis.

[0014] A further embodiment of the present invention is a composition wherein the expression vector comprises a heterologous mammalian targeting sequence. In specific embodiments, the mammalian targeting sequence is ubiquitin or a signal sequence for secretion.

[0015] Another specific embodiment of the present invention is a method of producing a DNA vaccine comprising the step of incubating an expression vector with an aggregated protein-polycationic polymer conjugate to form DNA particles wherein the expression vector comprises a promoter polynucleotide sequence operatively linked to a polynucleotide sequence encoding an antigen. In specific embodiments, the DNA vaccine is administered to a mucosal (*e.g.*, intranasal surface, oral surface, gastrointestinal surface and genitourinary tract surface) or parenteral surface (*e.g.*, intraperitoneal, intravenous, subcutaneous, intramusclar and intradermal) of an organism. Organisms that may be treated using the method of the invention include, but are not limited to humans, cows, horses, pigs, dogs, cats, sheep goats, rabbits, rats, mice, birds, monkeys, chickens or fish.

[0016] An additional embodiment of the present invention is the method of inducing an immune response in an organism comprising the step of administering to an organism the expression vector bound to an aggregated protein-polycationic polymer conjugate wherein the expression vector is comprises a promoter polynucleotide sequence operatively linked to a polynucleotide sequence encoding an antigen.

[0017] In specific embodiments, the method of inducing an immune response comprises the step of co-administering to an organism the expression vector bound to an aggregated protein-polycationic polymer conjugate and a cytokine expression vector.

[0018] In further embodiments, the method of inducing an immune response comprises the step of administering to an organism one expression vector bound to an aggregated protein-polycationic polymer conjugate, wherein the expression vector comprises a promoter polynucleotide sequence operatively linked to a first polynucleotide sequence encoding an antigen and a second polynucleotide sequence encoding a cytokine. In specific embodiments, the first and second polynucleotide sequences are under transcriptional control of the same promoter polynucleotide sequence. In other embodiments, the first and second polynucleotide sequences are under transcriptional control of different promoter polynucleotide sequences. One skilled in the art realizes that the polynucleotide sequences may be in tandem under control of the same promoter sequence or the polynucleotides are under control of separate promoter sequences.

[0019] A further embodiment of the present invention is the method of introducing genes into a cell comprising the steps of forming a DNA particle comprising an expression vector bound to an aggregated protein-polycationic polymer conjugate wherein the expression vector comprises a promoter polynucleotide sequence operatively linked to a polynucleotide sequence encoding an antigen, and incubating the cells with the DNA particle under conditions wherein the cells take in the DNA particle.

[0020] Another embodiment of the present invention is a composition comprising an expression vector incubated with a protein-polycationic polymer suspension, wherein the expression vector comprises a promoter polynucleotide sequence operatively linked to a polynucleotide sequence encoding an antigen.

[0021] Yet further, an additional embodiment of the present invention is the method of inducing an immune response in an organism comprising the step of administering to an organism an expression vector incubated with a protein-polycationic polymer suspension, wherein the expression vector is comprises a promoter

polynucleotide sequence operatively linked to a polynucleotide sequences encoding an antigen.

[0022] Other and further objects, features and advantages would be apparent and eventually more readily understood by reading the following specification and by reference to the company drawings forming a part thereof, or any examples of the present preferred embodiments of the invention are give for the purpose of the disclosure.

DESCRIPTION OF THE DRAWINGS

[0023] The following drawings form part of the present specification and are included to further demonstrate certain aspects of the present invention. The invention may be better understood by reference to one or more of these drawings in combination with the detailed description of specific embodiments presented herein.

[0024] Figure 1 shows the distribution of macroaggregated polyethyleneimine fluorescent particles in cross sections of lung tissue isolated from mice.

[0025] Figure 2A and 2B show cells in which green fluorescent protein (GFP) has been expressed. Figure 2A shows the cells under visible light. Figure 2B shows the same cells under UV light illuminating the fluorescent protein.

[0026] Figure 3 shows a graphical representation of the comparison between the transfection efficiency of MAA-PEI compared to Lipofectin. The black bars indicate that 10% fetal calf serum (FCS) was used in the medium. The white bars indicate that the medium was serum free.

[0027] Figures 4A, 4B and 4C show the total systemic humoral immune response to injection of pCMV-hGH bound to macroaggregated polyethyleneimine MAA-PEI. Figure 4A illustrates the total specific anti-hGH antibody. Figure 4B shows serial dilution of the individual serum from each mouse described in Figure 4A. In Figure 4A and 4B, the triangles represent the control samples, the diamonds represent the MAA-PEI-hGH samples and the squares represent the IM-hGH samples. Figure 4C shows the serial dilution as in Figure 4B from different set of experiments. In Figure 4C, the triangles represent the control samples, the diamonds represent the MAA-PEI-hGH samples and the squares represent the IV-hGH samples.

[0028] Figures 5A and 5B show the isotype distribution of the humoral response. Figure 5A illustrates the isotype specific antibody responses from 8 week pooled serum samples from the particle, intramusclar and control unimmunized groups. The gray bars represent control, the black bars represent MAA-PEI-hGH and the white bars represent IM-hGH. Figure 5B demonstrates the kinetics of the immune response with respect to isotype pooled samples from the 2, 6, and 12 week serum samples from the particle

group. The gray bars represent 2 weeks, the black bars represent 6 weeks and the white bars represent 12 week serum samples.

[0029] Figures 6A and 6B show pulmonary mucosal IgA response. Figure 6A illustrates the isotype specific anti-hGH antibody for IgA in the lavage fluid after 8 weeks in the following groups: control unimmunized mice and mice immunized with MAA-PEI-hGH plasmid, naked hGH plasmid, or PEI-hGH plasmid complexes. The triangles represent the control samples, the diamonds represent the MAA-PEI-hGH samples and the squares represent the IV-hGH samples. Figure 6B illustrates both IgA (white bars) and IgG (black bars) antibodies to hGH assayed in the bronchoalvedar lavage fluids.

[0030] Figures 7A and 7B show p18 specific CTL elicited by MAA-PEI-CMV-UB#23. Figure 7A illustrates the p18 Specific splenic cytotoxic T-lymphocytes. Direct CTL assays were performed with spleen cells at 8 weeks. Figure 7B shows the p18 specific IEL CTL elicited by MAA-PEI-CMV-UB#23 in intestinal epithelial lymphocytes. The triangles represent p18 targets and the squares represent no peptide targets.

[0031] Figure 8 shows genital mucosal IgA (black bars) induced by oral and syrijet plasmid administration. IgG is shown in the white bars.

[0032] Figure 9 shows the structure of HIV expression libraries. Expression immunization libraries were constructed by creating overlapping PCR fragments (400-600 bp) from each open reading frame in the HIV genome (Wang *et al.,* 1993). These fragments were then inserted into pCMV expression vectors as shown, with fusion to ubiquitin or hGH coding sequences, or without fusion to another expressed sequence.

[0033] Figures 10A and 10B shows the oral MAA-PEI bound UB23 plasmid elicits CTL in splenocytes (Figure 10A) and intestinal mononuclear cells (Figure 10B). The triangles represent p18 targets and the squares represent no peptide targets.

[0034] Figure 11 shows the intradermal injection of UB23 plasmid elicits CTL in total genital mononuclear cells.

[0035] Figures 12A and 12B illustrate the systemic and mucosal anti-p24 response after a single injection of particle associated plasmids. Figure 12A shows the mean and standard deviation of baseline (Week 0, white bars) and 9 week samples (black bars) from 6 monkeys. Figure 12B shows the baseline (white bars) and 12 week samples (3 weeks after boost, black bars) under similar conditions.

[0036] Figure 13 illustrates the T cell proliferative and cytokine production responses to peptide stimulation. The plot shows the percentage of monkeys responding to one or more peptides over the time course of the experiment (squares), and the total

number of individual responses to the different stimulating peptides and proteins in the group of monkeys at the different time points (diamonds).

[0037] Figure 14 shows the Rhesus macaque immune responses generated by two immunizations with the HIV-1 ELI vaccine.

[0038] Figures 15A and 15 B demonstrate the gene expression of a plasmid bound to non-conjugated HSA/PEI. Figure 15A shows the dose response curve for the quantity of injected DNA. Figure 15B shows the range of N:P ratios.

[0039] Figures 16A and 16B illustrates the kinetics of gene expression in repeated injections. Figure 16A shows the gene expression over time, 24 hrs, 48 hrs, 72 hrs and 96 hrs. Figure 16A shows the gene expression for 48 hrs with one, two or three injections within the 48 hrs.

[0040] Figures 17A and 17B shows the effects of different proteins and concentrations of proteins on PEI based gene delivery. Figure 17A shows the gene expression in the presence of a range of concentrations of HSA. Figure 17A shows the gene expression in the presence of other soluble proteins.

[0041] Figures 18A and 18B illustrates the organ distribution of gene expression. Figure 18A shows the distribution of gene expression using DNA bound to non-conjugated HSA/PEI. Figure 18B shows the distribution of gene expression using DNA bound to conjugated MAA-PEI.

DETAILED DESCRIPTION

[0042] It is readily apparent to one skilled in the art that various embodiments and modifications may be made to the invention disclosed in this Application without departing from the scope and spirit of the invention.

[0043] As used herein the specification, "a" or "an" may mean one or more. As used herein in the claim(s), when used in conjunction with the word "comprising", the words "a" or "an" may mean one or more than one. As used herein "another" may mean at least a second or more.

[0044] The term "aggregated protein" as used herein is defined as a protein that has been combined to form a large amorphous particle. Heat and chemical denaturation are the most common methods used to aggregate proteins. Exemplary proteins that can be a aggregated include but are not limited to, albumin, lysozyme, immunoglobulins, ribonuclease, alcohol dehydrogenase and human chorionic gonadotropin.

[0045] The term "antibody" as used herein is defined as a serum immunoglobulin that has specific binding sites to combine with antigens.

[0046] The term "antigen" as used herein is defined as a molecule that provokes an immune response. This immune response may involve either antibody production, the activation of specific immunologically-competent cells, or both. An antigen can be derived from organisms, subunits of proteins/antigens, killed or inactivated whole cells or lysates. Therefore, a skilled artisan realizes that any macromolecule, including virtually all proteins, can serve as antigens. Furthermore, antigens can be derived from recombinant DNA. A skilled artisan realizes that any recombinant DNA, which contains sequences or partial sequences of a pathogenic genome or a gene for a protein that elicits an immune response can result in synthesis of an antigen.

[0047] The term "autoimmune disease" as used herein is defined as a disorder that results from autoimmune responses. Autoimmunity is an inappropriate and excessive response to self-antigens. Examples include but are not limited to, Addision's disease, Graves' disease, Type I-Diabetes mellitus, Multiple sclerosis, Myxedema, Pernicious anemia, Rheumatic fever, Rheumatoid arthritis, Systemic lupus erythematous, and ulcerative colitis.

[0048] The term "cancer" as used herein is defined as a malignant cellular neoplasm (tumor) that invades other cells. Examples include but are not limited to, breast cancer, prostate cancer, ovarian cancer, cervical cancer, skin cancer, pancreatic cancer, colorectal cancer and lung cancer.

[0049] The terms "cell," "cell line," and "cell culture" as used herein may be used interchangeably. All of these terms also include their progeny, which are any and all subsequent generations. It is understood that all progeny may not be identical due to deliberate or inadvertent mutations.

[0050] The term "conjugate" as used herein is defined as molecules bound to each other via a covalent bond. One skilled in the art recognizes that the terms "conjugate" and "cross-link" are interchangeable.

[0051] The term "cytotoxic T-lymphocytes" as used herein is defined as cells that destroy cells displaying a specific antigen recognized by their surface receptors. These cytotoxic T-lymphocytes also release lymphotoxin.

[0052] The term "DNA" as used herein is defined as deoxyribonucleic acid.

[0053] The term "DNA particle" as used herein is defined as DNA bound to a protein-polycationic polymer conjugate. The DNA may be in the form of an expression vector or plasmid or a linear DNA fragment. One of skill in the art is cognizant that the DNA is bound to the conjugate via a non-covalent bond.

[0054] The term "expression" as used herein is defined as the transcription and/or translation of a particular polynucleotide sequence driven by its promoter.

[0055] The term "expression vector" as used herein refers to a vector containing a polynucleotide sequence coding for at least part of a gene product capable of being transcribed. In some cases, RNA molecules are then translated into a protein, polypeptide, or peptide. In other cases, these sequences are not translated, for example, in the production of antisense molecules or ribozymes. Expression vectors can contain a variety of control sequences, which refer to polynucleotide sequences necessary for the transcription and possibly translation of an operatively linked coding sequence in a particular host organism. In addition to control sequences that govern transcription and translation, vectors and expression vectors may contain polynucleotide sequences that serve other functions as well and are described infra. One skilled in the art realizes that an "expression vector" and a "plasmid" are interchangeable.

[0056] The term "expression library immunization" or "ELI" as used herein is defined as a library constructed by cloning overlapping fragments of a particular genome into a mammalian expression plasmid. Exemplary genomes include but are not limited to, Helicobacters, Campylobacters, Clostridia, *Corynebacterium diphtheriae*, *Bordetella pertussis*, influenza virus, parainfluenza viruses, respiratory syncytial virus, hepatitis viruses, *Borrelia burgdorfei*, Plasmodium, herpes simplex viruses, human immunodeficiency virus, papilloma virus, *Vibrio cholera*, *E. coli*, measles virus, rotavirus, shigella, *Salmonella typhi*, *Neisseria gonorrhea*.

[0057] The term "immunoglobulin" or "Ig", as used herein is defined as a class of proteins, which functions as antibodies. Two members in this class of proteins are IgA and IgG. IgA functions as the primary antibody that is present in body secretions, such as saliva, tears, breast milk, gastrointestinal secretions and mucus secretions of the respiratory and genitourinary tracts. IgG functions as the most common circulating antibody.

[0058] The term "pharmaceutically acceptable carrier" as used herein includes any and all solvents, dispersion media, coatings, surfactants, antioxidants, preservatives (*e.g.*, antibacterial agents, antifungal agents), isotonic agents, absorption delaying agents, salts, preservatives, drugs, drug stabilizers, gels, binders, excipients, disintegration agents, lubricants, sweetening agents, flavoring agents, dyes, such like materials and combinations thereof, as would be known to one of ordinary skill in the art (see, for example, Remington's Pharmaceutical Sciences, 18th Ed. Mack Printing Company, 1990, pp. 1289-1329, incorporated herein by reference). Except insofar as any conventional carrier is incompatible with the active ingredient, its use in the therapeutic or pharmaceutical compositions is contemplated.

[0059] The term "polycationic polymer" as used herein is defined as a water-soluble positively charged compound. The polycationic polymer neutralizes the negative

charge of the nucleic acids allowing close proximity of the nucleic acids to the negatively charge cell membrane. Exemplary polycationic polymers include but are not limited to, polylysine, polyethyleneimine, polyhistidine, protamine, polyvinylamines, polyvinylpyridine, polymethacrylates, and polyornithine. One of skill in the art is cognizant that polyehyleneimine and polyethylenimine are interchangeable.

[0060] The term "polynucleotide" as used herein is defined as a chain of polynucleotides. Furthermore, nucleic acids are polymers of polynucleotides. Thus, nucleic acids and polynucleotides as used herein are interchangeable. One skilled in the art has the general knowledge that nucleic acids are polynucleotides, which can be hydrolyzed into the monomeric "polynucleotides." The monomeric polynucleotides can be hydrolyzed into nucleosides. As used herein polynucleotides include, but are not limited to, all nucleic acid sequences which are obtained by any means available in the art, including, without limitation, recombinant means, *i.e.,* the cloning of nucleic acid sequences from a recombinant library or a cell genome, using ordinary cloning technology and PCR, and the like, and by synthetic means. Furthermore, one skilled in the art is cognizant that polynucleotides include, without limitation, mutations of the polynucleotides, including but not limited to, mutation of the polynucleotides, or nucleosides by methods well known in the art.

[0061] The term "promoter" as used herein is defined as the region of polynucleotide sequence, which regulates transcription of a specific polynucleotide sequence. The term promoter includes enhancers, silencers and other cis-acting regulatory elements. One of skill in the art is cognizant that the "promoter" refers to the nucleotide sequence recognized by the synthetic machinery of the cell, or introduced synthetic machinery, required to initiate the specific transcription of a gene.

[0062] The term "RNA" as used herein is defined as ribonucleic acid.

[0063] The term "recombinant DNA" as used herein is defined as DNA produced by joining pieces of DNA from different sources.

[0064] The term "recombinant polypeptide" as used herein is defined as a hybrid protein produced by using recombinant DNA methods.

[0065] The term "transfected" or "transformed" or "transduced" as used herein refers to a process by which exogenous nucleic acid is transferred or introduced into the host cell. A transformed cell includes the primary subject cell and its progeny.

[0066] The phrase "under transcriptional control" or "operatively linked" as used herein means that the promoter is in the correct location and orientation in relation to the polynucleotide sequence to control RNA polymerase initiation and expression of the gene.

[0067] The term "vaccine" as used herein is defined as material used to provoke an immune response (*e.g.*, the production of antibodies) on administration of the materials and thus conferring immunity.

[0068] The term "virus" as used herein is defined as a particle consisting of polynucleotide sequences (RNA or DNA) enclosed in a protein coat, with or without an outer lipid envelope, which is only capable of replicating within a whole cell and spreading from cell to cell.

[0069] One embodiment of the present invention is a composition comprising an expression vector bound to an aggregated protein-polycationic polymer conjugate, wherein the expression vector comprises a promoter polynucleotide sequence operatively linked to a polynucleotide sequence encoding an antigen.

[0070] In preferred embodiments, the polynucleotide sequence encoding an antigen product is under transcriptional control of a promoter. Much of the thinking about how promoters are organized derives from analyses of several viral promoters, including those for the HSV thymidine kinase (tk) and SV40 early transcription units. These studies, augmented by more recent work, have shown that promoters are composed of discrete functional modules, each consisting of approximately 7-20 bp of DNA, and containing one or more recognition sites for transcriptional activator or repressor proteins.

[0071] At least one module in each promoter functions to position the start site for RNA synthesis. The best known example of this is the TATA box, but in some promoters lacking a TATA box, such as the promoter for the mammalian terminal deoxynucleotidyl transferase gene and the promoter for the SV40 genes, a discrete element overlying the start site itself helps to fix the place of initiation.

[0072] Additional promoter elements regulate the frequency of transcriptional initiation. Typically, these are located in the region 30-110 bp upstream of the start site, although a number of promoters have recently been shown to contain functional elements downstream of the start site as well. The spacing between promoter elements frequently is flexible, so that promoter function is preserved when elements are inverted or moved relative to one another. In the tk promoter, the spacing between promoter elements can be increased to 50 bp apart before activity begins to decline. Depending on the promoter, it appears that individual elements can function either co-operatively or independently to activate transcription.

[0073] The particular promoter that is employed to control the expression of a polynucleotide sequence encoding an antigen is not believed to be important, so long as it is capable of expressing the polynucleotide sequence in the targeted cell. Thus, where a human cell is targeted, it is preferable to position the polynucleotide sequence coding region adjacent to and under the control of a promoter that is capable of being expressed

in a human cell. Generally speaking, such a promoter might include either a human or viral promoter.

[0074] In various embodiments, the human cytomegalovirus (CMV) immediate early gene promoters, the SV40 early promoter and the Rous sarcoma virus long terminal repeat can be used to obtain high-level expression of the antigen of interest. The use of other viral or mammalian cellular bacterial phage promoters which are well-known in the art to achieve expression of a specific antigen are contemplated as well, provided that the levels of expression are sufficient for a given purpose.

[0075] By employing a promoter with well-known properties, the level and pattern of expression of a specific gene can be optimized. For example, selection of a promoter which is active specifically in lung cells, such as tyrosinase (melanoma), alpha-fetoprotein and albumin (liver tumors), CC10 (lung tumor) and prostate-specific antigen (prostate tumor) will permit tissue-specific expression of a specific gene. Further, selection of a promoter that is regulated in response to specific physiologic signals can permit inducible expression of a specific gene. Several elements/promoters which may be employed, in the context of the present invention, to regulate the expression of a specific gene.

[0076] Enhancers were originally detected as genetic elements that increased transcription from a promoter located at a distant position on the same molecule of DNA. This ability to act over a large distance had little precedent in classic studies of prokaryotic transcriptional regulation. Subsequent work showed that regions of DNA with enhancer activity are organized much like promoters. That is, they are composed of many individual elements, each of which binds to one or more transcriptional proteins.

[0077] The basic distinction between enhancers and promoters is operational. An enhancer region as a whole must be able to stimulate transcription at a distance; this need not be true of a promoter region or its component elements. On the other hand, a promoter must have one or more elements that direct initiation of RNA synthesis at a particular site and in a particular orientation, whereas enhancers lack these specificities. Promoters and enhancers are often overlapping and contiguous, often seeming to have a very similar modular organization.

[0078] In specific embodiments of this invention, the expression vector is bound to an aggregated protein-polycationic polymer conjugate. The conjugate of an aggregated protein and a polycationic polymer makes an attractive delivery vehicle. Polycations, which are water-soluble complexes, are known in the art and have been utilized as a delivery system for DNA plamids. This strategy employs the use of a soluble system, which will convey the DNA into the cells via a receptor-mediated endocytosis (Wu & Wu 1988). For prior art to be successful, however, specific ligands or receptors must be

conjugated to a polycation. The present invention is different and one skilled in the art realizes that the combination of the polycation will help neutralize the negative charge of the nucleic acid allowing increased endocytic uptake and the aggregated protein will aid in the particulate formation allowing the DNA to be taken up by the endothelial cells in the capillary bed; thus eliminating the necessity of targeting a specific cell surface receptor.

[0079] One embodiment of the present invention is that the bond between the aggregated protein-polycationic polymer is a covalent bond. For example, but not limited to, the protein is conjugated to the polycationic polymer via cross-linking an amine group to a thiol group. One skilled in the art realizes that there are several methods available to conjugate molecules. Exemplary conjugating or cross-linking methods include, but are not limited to thiol-thiol cross-linking, amine-amine cross-linking and amine-thiol cross-linking. After the conjugate is formed, the protein is aggregated.

[0080] A further embodiment of the present invention is that the expression vector is bound to the aggregated protein-polycationic polymer conjugate. One skilled in the art is cognizant that the bond between the conjugate and the expression vector or DNA is a non-covalent bond. Exemplary non-covalent bonds include, but are not limited to charge-charge interaction, charge-dipole interaction, dipole-dipole interaction, charge-induced dipole interaction, dipole-induced dipole interaction, dispersion, and hydrogen bond. In specific embodiments, the non-covalent bond is a charge-charge interaction.

[0081] In further specific embodiments, the expression vector is bound to a suspension of a protein and a polycationic polymer. The protein and the polycationic polymer are not conjugated, however, they are bound via a charge-charge interaction. Thus, a skilled artisan realizes that conjugation of the protein and polycationic polymer is not essential under all circumstances for efficient delivery of the DNA. The expression vector or DNA is combined under appropriate conditions in a suspension with a protein and a polycationic polymer and the suspension can be administered to the animal. In specific embodiments, the protein is not aggregated.

[0082] Furthermore, skilled artisans recognize that a particulate form of a DNA vaccine can be used to more efficiently target antigen-presenting cells. In general, the range of possible targets for a particulate DNA vaccine is dependent on the route of injection (*e.g.*, intravenous or intra-arterial, subcutaneous, intra-peritoneal, intrathecal or oral). For systemic injections, the specificity of this particulate delivery system is affected by the accessibility of the target to blood borne particles, which in turn, is affected by the size range of the particles. Temperature, particle concentration, and pH affect the size of the particles. The particles can also be size-fractionated (*e.g.*, by sucrose gradient ultracentrifugation). Particles with size less than 150 nanometers can access the

interstitial space by traversing through the fenestrations that line most blood vessels walls. Hydrophilic particles with sizes greater than 0.2 microns may cross the capillary wall by endocytosis at the luminal surface, vesicular transport through cytoplasm and exocytosis at the other side where the molecule passes through the interstitial space to target macrophages and dendritic cells. In the present invention, the target size of the particles is within the range of about 0.05-50 microns.

[0083] For oral delivery, the target cells include but are not limited to, the M cells or absorptive epithelial cells. A skilled artisan realizes that the particulate DNA is engulfed by the M cells, which covers the mucosal inductive sites, and is channeled to parenchymal macrophages, dendritic cells, B lymphocytes, mast cells, and/or they can be processed and perhaps presented directly by the epithelial cells to the underlying B and T cells. Furthermore, a skilled artisan recognizes the inductive sites of the mucosal surface include the Peyer's patches in the small intestine, the appendix and solitary follicles in the large intestine and rectum, the nasal mucosa and the tonsils in the upper aerodigestive tract (Czerkinsky *et al.*, 1999). These sites serve as the primary sources of precursor cells that migrate through the lymphatic and circulatory system.

[0084] Furthermore, the ratio of nucleic acids to conjugate can vary within a wide range, and it is not absolutely necessary to neutralize all the charges of the nucleic acids. This ratio will have to be adjusted for each individual case depending on criteria such as the size and structure of the nucleic acids, the size of the polycation and the number and distribution of its charges, so as to achieve a ratio of transportability and biological activity of the nucleic acids which is favorable to the particular application. This ratio can first of all be adjusted coarsely, for example by using the delay in the speed of migration of the DNA in a gel (*e.g.*, using the mobility shift on an agarose gel) or by density gradient centrifugation. Once this provisional ratio has been obtained, it may be expedient to carry out transporting tests with labeled complexes, *e.g.*, radioactive isotopes, stable isotopes, or fluorescent tags, with respect to the maximum available activity of the nucleic acid in the cell and then reduce the proportion of conjugate if necessary so that the remaining negative charges of the nucleic acid are not an obstacle to transportation into the cell.

[0085] In a specific embodiment of the present invention, the polynucleotide sequence encoding the antigen is a fragment of a genome or gene selected from the group of genomes or genes associated with a disease consisting of infectious disease, cancer and autoimmune disease. More particularly, the polynucleotide sequence encoding the antigen is a fragment of a genome selected from the group of pathogenic genomes consisting of virus, bacterium, fungus and protozoa. In specific embodiments, the polynucleotide sequence encoding the antigen is a fragment of a genome selected from the group viral genomes consisting of human immunodeficiency virus (HIV), herpes

simplex virus (HSV) hepatitis C virus (HCV), influenza virus and respiratory syncytial virus (RSV). In a further embodiment of the present invention, the polynucleotide sequence encoding the antigen is a fragment of a gene selected from the group of genes associated with an autoimmune disease consisting of rheumatoid arthritis, vaculitis, and multiple sclerosis.

[0086] The following polynucleotide sequences are representative sequences corresponding to HIV, HSV, HCV, influenza virus or RSV genomes or fragments of the genomes and are within the scope of the invention and some are referenced with the corresponding GenBank Accession Numbers (http://www.ncbi.nlm.nih.gov/Genbank/GenbankSearch.html): U23 (SEQ.ID.NO:1); AF041850: SHIV-HXBc2P 3.2, complete (SEQ.ID.NO:3); U12055: HIV-1, isolate LW12.3, lab worker, complete genome (SEQ.ID.NO:4); M76764: SHIV clone 1A11, complete genome (SEQ.ID.NO:5); NC_001433: Hepatitis C virus, complete genome (SEQ.ID.NO:6); AF290978: Hepatitis C virus isolate colonel complete genome (SEQ.ID.NO:7); NC_001798: Human herpesvirus 2, complete genome (SEQ.ID.NO:8); NC_001781: Human respiratory syncytial virus, complete genome (SEQ.ID.NO:10); AF321523: HIV-1 clone MJ4 from Botswana, complete genome (SEQ.ID.NO:11) and K02007: HIV-1, isolate ARV-2/SF2, complete proviral genome; (SEQ.ID.NO:12). One of skill in the art is cognizant that the above sequences are representative sequences of several pathogenic genomes. It is well known and understood that standard methods of molecular biology can be used to isolate and clone a sequence of any pathogen of interest and to use this sequence in the present invention.

[0087] This invention utilizes the technique of expression library immunization to construct the recombinant plasmids that are used to induce an immune response. This technique has been used to produce immunologic responses similar to live vaccines without the risk of reversion to pathogenic viruses. The ELI is constructed by cloning overlapping fragments of the antigenic genome or gene (genomic DNA or cDNA) of interest into mammalian expression plasmids. Therefore, a skilled artisan realizes that any genome, gene and fragments of genomes and genes associated with infectious disease, cancer or autoimmune disease can be used to construct an ELI and this DNA plasmid or plasmids can be used in the present invention to induce an immune response. In addition to the above-mentioned possibilities for ELI, another possibility is the use of a gene that is important in regulatory processes at the mucosal surface. For example, interleukin 5 and interleukin 13 are thought to play a regulatory role in asthma. Therefore, an ELI could be constructed to IL-5 or IL-13 and used as a potential vaccine to treat asthma.

[0088] A further embodiment of the present invention is a composition wherein the expression vector comprises a heterologous mammalian targeting sequence. In

specific embodiments, the mammalian targeting sequence is ubiquitin or a signal sequence for secretion. Skilled artisans recognize that the use of particular targeting sequences direct the antigen to particular compartments within the cell. It has been documented that the insertion downstream of a ubiquitin sequence enhanced the cytotoxic lymphocyte response because the ubiquitin sequence targets the antigen to the proteasome for degradation and presentation via the MHC class I pathway. However, the addition of a signal sequence for secretion, specifically targets the antigen for secretion, which allows for presentation via the MHC type II pathway or B lymphocytes. Exemplary proteins, which contain signal sequences for secretion, that could be used to target the antigen for secretion include but are not limited to, hormones, cytokines, neurotransmitters, and immunoglobulins. Thus, skilled artisans realize that any targeting sequence can be substituted in the present invention to achieve the desired response.

[0089] Another specific embodiment of the present invention is a method of producing a DNA vaccine comprising the step of forming a DNA particle comprising an expression vector bound to an aggregated protein-polycationic polymer conjugate. In specific embodiments, the DNA vaccine will be administered to a mucosal (*e.g.*, intranasal surface, oral surface, gastrointestinal surface and genitourinary tract surface) or parenteral surface (*e.g.*, intraperitoneal, intravenous, subcutaneous, intramusclar and intradermal) of an organism. A skilled artisan recognizes the importance of developing mucosal immunization methods because the majority of deaths from infectious diseases are caused by organisms that first make contact with and either colonize or cross the mucosal surface to infect the host. Therefore, for many infections, such as HIV, a vaccine that does not prevent the initial infection of the host will unlikely succeed in resolving the infection before the disease ensues. Mucosal immunization induces IgA antibodies, which are directed against specific pathogens of mucosal surfaces. It is suggested in the art that greater than 80% of all the antibodies produced in mucosal-associated lymphoid tissues may block attachment of bacteria and viruses. This blockade neutralizes bacterial toxins and inactivates invading viruses inside the epithelial cells. Therefore, a skilled artisan can readily recognize that mucosal immunization would actually prevent the initial infection resulting in a decrease in the morbidity caused by pathogens.

[0090] An additional embodiment of the present invention is the method of inducing an immune response comprising the step of administering to an organism the expression vector bound to an aggregated protein-polycationic polymer conjugate wherein the expression vector comprises a promoter polynucleotide sequence, and a polynucleotide sequence encoding an antigen, operatively linked.

[0091] In specific embodiments, the method of inducing an immune response comprises the step of co-administering to an organism the expression vector and a cytokine expression vector. A number of studies have shown that the responses to

individual plasmids can be enhanced by co-administration of a cytokine expressing plasmid. It should be noted that picogram to nanogram quantities of locally synthesized cytokine from the expression vector are too low to have systemic effects on the whole animal, but can still strongly influence the local cytokine environment and thus the immune response to the administered antigen. A skilled artisan readily recognizes that the polynucleotide sequences for a cytokine and the polynucleotide sequences for the antigen can be incorporated into one expression vector; thus eliminating the use of two separate vectors. In addition to cytokines, plasmids that contain ummethylated CpG sequences enhance the cell mediated (Th1) response (Carson *et al.*, 1997). CpG sequence motifs include but are not limited to, RRCpGYY. Thus, a skilled artisan realizes that supplementation of a cytokine with the expression vector or addition of a CpG sequence motif in the present invention would result in the enhancement of the immune response.

[0092] A further embodiment of the present invention is the method of introducing genes into a cell comprising the steps of forming a DNA particle comprising an expression vector bound to an aggregated protein-polycationic polymer conjugate wherein the expression vector comprises a promoter polynucleotide sequence, and a polynucleotide sequence encoding an antigen, operatively linked and incubating the cells with the DNA particle under conditions wherein the cells take in the DNA particle.

Dosage and Formulation

[0093] The compounds (active ingredients) of this invention can be formulated and administered to treat a variety of disease states by any means that produces contact of the active ingredient with the agent's site of action in the body of the organism. They can be administered by any conventional means available for use in conjunction with pharmaceuticals, either as individual therapeutic active ingredients or in a combination of therapeutic active ingredients. They can be administered alone, but are generally administered with a pharmaceutical carrier selected on the basis of the chosen route of administration and standard pharmaceutical practice.

[0094] The dosage administered will be a therapeutically effective amount of active ingredient and will, of course, vary depending upon known factors such as the pharmacodynamic characteristics of the particular active ingredient and its mode and route of administration; age, sex, health and weight of the recipient; nature and extent of symptoms; kind of concurrent treatment, frequency of treatment and the effect desired.

[0095] The active ingredient can be administered orally in solid dosage forms such as capsules, tablets and powders, or in liquid dosage forms such as elixirs, syrups, emulsions and suspensions. The active ingredient can also be formulated for administration parenterally by injection, rapid infusion, nasopharyngeal absorption or

dermoabsorption. The agent may be administered intramuscularly, intravenously, or as a suppository.

[0096] Gelatin capsules contain the active ingredient and powdered carriers such as lactose, sucrose, mannitol, starch, cellulose derivatives, magnesium stearate, stearic acid, and the like. Similar diluents can be used to make compressed tablets. Both tablets and capsules can be manufactured as sustained release products to provide for continuous release of medication over a period of hours. Compressed tablets can be sugar coated or film coated to mask any unpleasant taste and protect the tablet from the atmosphere, or enteric coated for selective disintegration in the gastrointestinal tract.

[0097] Liquid dosage forms for oral administration can contain coloring and flavoring to increase patient acceptance.

[0098] In general, water, suitable oil, saline, aqueous dextrose (glucose), and related sugar solutions and glycols such as propylene glycol or polyethylene glycols are suitable carriers for parenteral solutions. Solutions for parenteral administration contain the active ingredient, suitable stabilizing agents and, if necessary, buffer substances. Antioxidizing agents such as sodium bisulfate, sodium sulfite or ascorbic acid, either alone or combined, are suitable stabilizing agents. Also used are citric acid and its salts and sodium Ethylenediaminetetraacetic acid (EDTA). In addition, parenteral solutions can contain preservatives such as benzalkonium chloride, methyl- or propyl-paraben and chlorobutanol. Suitable pharmaceutical carriers are described in *Remington's Pharmaceutical Sciences*, a standard reference text in this field.

[0099] Additionally, standard pharmaceutical methods can be employed to control the duration of action. These are well known in the art and include control release preparations and can include appropriate macromolecules, for example polymers, polyesters, polyamino acids, polyvinyl, pyrolidone, ethylenevinylacetate, methyl cellulose, carboxymethyl cellulose or protamine sulfate. The concentration of macromolecules as well as the methods of incorporation can be adjusted in order to control release. Additionally, the agent can be incorporated into particles of polymeric materials such as polyesters, polyamino acids, hydrogels, poly (lactic acid) or ethylenevinylacetate copolymers. In addition to being incorporated, these agents can also be used to trap the compound in microcapsules.

[0100] Useful pharmaceutical dosage forms for administration of the compounds of this invention can be illustrated as follows.

[0101] Capsules: Capsules are prepared by filling standard two-piece hard gelatin capsulates each with 100 milligram of powdered active ingredient, 175 milligrams of lactose, 24 milligrams of talc and 6 milligrams magnesium stearate.

[0102] Soft Gelatin Capsules: A mixture of active ingredient in soybean oil is prepared and injected by means of a positive displacement pump into gelatin to form soft gelatin capsules containing 100 milligrams of the active ingredient. The capsules are then washed and dried.

[0103] Tablets: Tablets are prepared by conventional procedures so that the dosage unit is 100 milligrams of active ingredient. 0.2 milligrams of colloidal silicon dioxide, 5 milligrams of magnesium stearate, 275 milligrams of microcrystalline cellulose, 11 milligrams of cornstarch and 98.8 milligrams of lactose. Appropriate coatings may be applied to increase palatability or to delay absorption.

[0104] Injectable: A parenteral composition suitable for administration by injection is prepared by stirring 1.5% by weight of active ingredients in 10% by volume propylene glycol and water. The solution is made isotonic with sodium chloride and sterilized.

[0105] Suspension: An aqueous suspension is prepared for oral administration so that each 5 milliliters contain 100 milligrams of finely divided active ingredient, 200 milligrams of sodium carboxymethyl cellulose, 5 milligrams of sodium benzoate, 1.0 grams of sorbitol solution U.S.P. and 0.025 milliliters of vanillin.

[0106] Accordingly, the pharmaceutical composition of the present invention may be delivered via various routes and to various sites in an animal body to achieve a particular effect (see, *e.g.*, Rosenfeld et al. (1991), supra; Rosenfeld *et al.*, Clin. Res., 39(2), 311A (1991a); Jaffe *et al.*, supra; Berkner, supra). One skilled in the art will recognize that although more than one route can be used for administration, a particular route can provide a more immediate and more effective reaction than another route. Local or systemic delivery can be accomplished by administration comprising application or instillation of the formulation into body cavities, inhalation or insufflation of an aerosol, or by parenteral introduction, comprising intramuscular, intravenous, peritoneal, subcutaneous, intradermal, as well as topical administration.

[0107] The composition of the present invention can be provided in unit dosage form wherein each dosage unit, *e.g.*, a teaspoonful, tablet, solution, or suppository, contains a predetermined amount of the composition, alone or in appropriate combination with other active agents. The term "unit dosage form" as used herein refers to physically discrete units suitable as unitary dosages for human and animal subjects, each unit containing a predetermined quantity of the compositions of the present invention, alone or in combination with other active agents, calculated in an amount sufficient to produce the desired effect, in association with a pharmaceutically acceptable diluent, carrier, or vehicle, where appropriate. The specifications for the unit dosage forms of the present

invention depend on the particular effect to be achieved and the particular pharmacodynamics associated with the pharmaceutical composition in the particular host.

[0108] These methods described herein are by no means all-inclusive, and further methods to suit the specific application will be apparent to the ordinary skilled artisan. Moreover, the effective amount of the compositions can be further approximated through analogy to compounds known to exert the desired effect.

Gene Therapy Administration

[0100] One skilled in the art recognizes that the mode of DNA delivery of this invention could potentially be used to deliver DNA to specific cells for gene therapy. For gene therapy, a skilled artisan would be cognizant that the vector to be utilized must contain the gene of interest operatively limited to a promoter. For antisense gene therapy, the antisense sequence of the gene of interest would be operatively linked to a promoter. One skilled in the art recognizes that in certain instances other sequences such as a 3′ UTR regulatory sequences are useful in expressing the gene of interest. Where appropriate, the gene therapy vectors can be formulated into preparations in solid, semisolid, liquid or gaseous forms in the ways known in the art for their respective route of administration. Means known in the art can be utilized to prevent release and absorption of the composition until it reaches the target organ or to ensure timed-release of the composition. A pharmaceutically acceptable form should be employed which does not ineffectuate the compositions of the present invention. In pharmaceutical dosage forms, the compositions can be used alone or in appropriate association, as well as in combination, with other pharmaceutically active compounds. A sufficient amount of vector containing the therapeutic nucleic acid sequence must be administered to provide a pharmacologically effective dose of the gene product.

[0110] One skilled in the art recognizes that different methods of delivery may be utilized to administer a vector into a cell. Examples include: (1) methods utilizing physical means, such as electroporation (electricity), a gene gun (physical force) or applying large volumes of a liquid (pressure); and (2) methods wherein the vector is complexed to another entity, such as a liposome, aggregated protein or transporter molecule.

[0111] Accordingly, the present invention provides a method of transferring a therapeutic gene to a host, which comprises administering the vector of the present invention, preferably as part of a composition, using any of the aforementioned routes of administration or alternative routes known to those skilled in the art and appropriate for a particular application. Effective gene transfer of a vector to a host cell in accordance with the present invention to a host cell can be monitored in terms of a therapeutic effect (e.g. alleviation of some symptom associated with the particular disease being treated) or,

further, by evidence of the transferred gene or expression of the gene within the host (*e.g.*, using the polymerase chain reaction in conjunction with sequencing, Northern or Southern hybridizations, or transcription assays to detect the nucleic acid in host cells, or using immunoblot analysis, antibody-mediated detection, mRNA or protein half-life studies, or particularized assays to detect protein or polypeptide encoded by the transferred nucleic acid, or impacted in level or function due to such transfer).

[0112] These methods described herein are by no means all-inclusive, and further methods to suit the specific application will be apparent to the ordinary skilled artisan. Moreover, the effective amount of the compositions can be further approximated through analogy to compounds known to exert the desired effect.

[0113] Furthermore, the actual dose and schedule can vary depending on whether the compositions are administered in combination with other pharmaceutical compositions, or depending on interindividual differences in pharmacokinetics, drug disposition, and metabolism. Similarly, amounts can vary in *in vitro* applications depending on the particular cell line utilized (*e.g.*, based on the number of vector receptors present on the cell surface, or the ability of the particular vector employed for gene transfer to replicate in that cell line). Furthermore, the amount of vector to be added per cell will likely vary with the length and stability of the therapeutic gene inserted in the vector, as well as also the nature of the sequence, and is particularly a parameter which needs to be determined empirically, and can be altered due to factors not inherent to the methods of the present invention (for instance, the cost associated with synthesis). One skilled in the art can easily make any necessary adjustments in accordance with the exigencies of the particular situation.

[0114] It is possible that cells containing the therapeutic gene may also contain a suicide gene (*i.e.*, a gene which encodes a product that can be used to destroy the cell, such as herpes simplex virus thymidine kinase). In many gene therapy situations, it is desirable to be able to express a gene for therapeutic purposes in a host cell but also to have the capacity to destroy the host cell once the therapy is completed, becomes uncontrollable, or does not lead to a predictable or desirable result. Thus, expression of the therapeutic gene in a host cell can be driven by a promoter although the product of the suicide gene remains harmless in the absence of a prodrug. Once the therapy is complete or no longer desired or needed, administration of a prodrug causes the suicide gene product to become lethal to the cell. Examples of suicide gene/prodrug combinations which may be used are Herpes Simplex Virus-thymidine kinase (HSV-tk) and ganciclovir, acyclovir or FIAU; oxidoreductase and cycloheximide; cytosine deaminase and 5-fluorocytosine; thymidine kinase thymidilate kinase (Tdk::Tmk) and AZT; and deoxycytidine kinase and cytosine arabinoside.

EXAMPLES

[0115] The following examples are included to demonstrate preferred embodiments of the invention. It should be appreciated by those of skill in the art that the techniques disclosed in the examples which follow represent techniques discovered by the inventor to function well in the practice of the invention, and thus can be considered to constitute preferred modes for its practice. However, those of skill in the art should, in light of the present disclosure, appreciate that many changes can be made in the specific embodiments which are disclosed and still obtain a like or similar result without departing from the spirit and scope of the invention.

EXAMPLE 1

Strains of Mice and Treatment of Mice

[0116] Female BALB/c mice were used for most studies where mucosal immune responses in the genital tract required collection of surface fluids for antibodies and effector cells for CTL assay from the target tissues. Male mice were used in limited studies. C57BL/6, SKH and CD-1 mouse strains were also studied in a limited number of experiments. Serum samples were obtained by tail bleeds, and vaginal and intestinal secretion samples were obtained by the wick method (Haneberg *et al.,* 1994). Mice were sacrificed at the desired time points by lethal anesthesia and exsanguination via cardiac puncture. Intestinal IELs and splenocytes were recovered by standard techniques, mincing the tissue by forcing it though cell strainer (Becton-Dickinson, Franklin Lakes, NJ). Mucosal tissues were subjected to a brief incubation with collagenase, and then mononuclear cells were separated by centrifugation over ficoll/hypaque. Genital mucosa lymphocyte isolation used similar methods, 3 x 10^6 mononuclear cells were recovered from the genital tissues excised from a group of 4 female mice.

EXAMPLE 2

Macroaggregated Albumin and Plasmid Binding

[0117] Macroaggregated albumin (MAA) was prepared following a standard protocol (Colombetti *et al.,* 1975). In brief, N-succinimidyl 3-(2-pyridyldithio)propionate (SPDP) was added to bovine serum albumin (BSA) or human serum albumin (HSA) and to polyethyleneimine (PEI) 750 kD; other sizes were treated in a similar manner) in a 15:1 mole ratio at pH 8 or above, reducing the PEI-SPDP at pH 7-7.5 with Reductacryl and adding it to BSA-SPDP at pH 7-7.5 in a 1:2 mole ratio. Aggregation was done at pH 5.5-6, and the aggregates were gently centrifuged, resuspended and rinsed with PBS for final use. In detail, 25 µL of a 20 mg/mL solution of SPDP in DMSO was added to 10 mL of a 10 mg/mL solution of BSA in 0.1 M $NaHCO_3$. Stirring was continued for 2 h. A solution of 144 mg of a 50% (w/w) of PEI in 2 mL of 0.1 M $NaHCO_3$ was prepared, and treated

with 25 μL of the SPDP solution. After 2 h of stirring, the PEI solution was divided and put over 2 NAP-10 columns which was equilibrated in phosphate buffered saline (PBS), pH 7.4. The combined effluents (3 mL) were stirred with 10 mg of Reductacryl for 1 h. The pH of 5 mL of the BSA-SPDP solution was adjusted to 7-7.5 (pH 4.5-10 test strips) with HCl, and 0.75 mL of the reduced, filtered PEI solution was added. The pH was further adjusted if necessary and the combined solutions incubated for 3 h. The pH was adjusted to 6-6.5 with 10% HCl, and the aggregation was accomplished at 70-75°C (thermometer in solution) for 5-10 min. The MAA-PEI particles were centrifuged down gently in microfuge tubes, and rinsed twice with PBS, pH 7.4. For plasmid binding, the particles were diluted in PBS to the desired volume, and the plasmid (diluted in PBS to 200 ng/μL) was added dropwise with gentle vortexing of the particle suspension. The suspension was then incubated at room temperature (RT) for 20 minutes before administration to the mice.

[0118] SPDP is a heterobifunctional crosslinking reageant. It crosslinks an amine group on one molecule, *i.e.,* polyethyleneimine, to a thiol group on a second molecule, *i.e.,* albumin. However, one skilled in the art recongizes that there are several methods available to conjugate molecules. Exemplary crosslinking methods include, but are not limited to, thiol-thiol crosslinking, *i.e.,* fluorescent cross-linkers; amine-amine crosslinking, *i.e.,* formaldehyde and glutaraldehyde, fluroescent bis(succinimidyl ester); and amine-thiol crosslinking, *i.e.,* SPDP.

Example 3

Macroaggregated Albumin (MAA) Distribution in Mouse Lung

[0119] To determine where functionalized MAA localized in lung tissue, MAA conjugated to low molecular weight polylysine was prepared using polylysine labeled with fluorescein isothiocyanate by standard methods (Colombetti *et al.,* 1975). Briefly, 5 mL of a 10 mg/mL solution of bovine serum albumin (BSA) was prepared. The particles were gently centrifuged, and resuspended twice in 0.1 M $NaHCO_3$. The particles were transferred to a flask and gently stirred while adding 30 μL of a solution of N-succinimidyl 3-(2-pyridyldithio) propionate (SPDP) (30 mg/mL, ca. 3:1 molar ratio SPDP:BSA). After the particles had stirred for 1 h, they were washed with 10 mM phosphate buffer pH 7.4, 0.150 M NaCl (PBS) using gentle centrifugation and resuspended to a volume of 4 mL. Solutions of polyethyleneimine (PEI) and polylysine (MW 10-20,000) were prepared in 0.1 M NaHCO3and functionalized with SPDP and fluorescein isothiocyanate (FITC), using a 3:1 and 1:1 molar ratio respectively. These solutions were rid of unreacted SPDP and FITC by elution from a NAP-5 column (Pharmacia). The SH groups were released by treatment with dithiothreitol (DTT) at pH 4.5 for 1 hr. The excess DTT was removed and the buffer changed to PBS by elution

from a NAP-5 column. The SH functionalized polycation was immediately added to the SPDP functionalized MAA with gentle stirring. The molar ratio of BSA to polycation was ca. 1:1. The brightly fluorescent green particles were washed with PBS before use. When the polycation was not functionalized with FITC, the release of the SH groups was accomplished with Reductacryl (CalBiochem) in PBS, and the solution added directly to the MAA.

[0120] To demonstrate successful conjugation of the MAA without FITC and binding of DNA, an oligopolynucleotide labeled with FITC was added at 1 μM to the particle suspensions, and then washed and examined under UV illumination. Fluorescent particles in the range of 10 to 100 μm diameter were present in the MAA-PEI and MAA-polylysine conjugates, while unconjugated MAA incubated with the oligopolynucleotide showed no fluorescence.

[0121] Once the MAA particles were prepared by the above procedure, BALB/c mice were injected via tail vein with 200 μL of the particulate suspension (2×10^4 particles/mL in the 50 to 100 μm size range), and then sacrificed after either 20 or 120 minutes. The lungs were prepared by inflating with embedding medium, and 40 μm thick frozen sections were examined by fluorescence microscopy. Brightly fluorescent particles were readily appreciated in alveolar septae where loose collections of macrophages and lymphocytes reside in the interstitial space (Hasleton *et al.*, 1996). The low level autofluorescence of lung tissue was not apparent with partial visual light illumination, but was easily distinguished from the bright fluorescence of the MAA particles under UV illumination alone (Figure 1). Examination of samples from multiple lung areas demonstrated a similar pattern, corresponding to the expected blood flow in the mouse, with relatively even distribution of the particles throughout the lung fields. There were no differences in particle appearance between samples obtained from mice sacrificed 20 minutes and 120 minutes after injection.

Example 4

Transfection of Cell Lines by MAA – Plasmid Particles Using Serum Free Medium

[0122] MAA was prepared and conjugated to polyethyleneimine according to Example 2, and then diluted to approximately 10^4 particles/mL in PBS. Plasmid DNA (pCMVßGal) was added at 2 μg/50 μL of particulate suspension and briefly incubated before diluting into serum free medium (Optimem, Gibco) at 50 μL/1.5 mL. T47D breast carcinoma cells grown to confluence in 6 well plates were washed with PBS, and then incubated for 24h with the MAA suspension in Optimem, and compared with liposome transfection using Lipofectin (Gibco) complexed with the plasmid. The cells were assayed for ß-galactosidase, and roughly 20-30% of cells in the MAA cultures showed enzymatic activity, compared to about 50% of the cells transfected by liposomes.

[0123] In a similar experiment, MAA was prepared and conjugated to polyethyleneimine, and then diluted to approximately 10^4 particles/mL in PBS. To bind pEGFP (encoding green fluorescnet protein, GFP) plasmid to MAA-PEI, the particles were diluted in PBS, and then an appropriate concentration of plasmid in PBS (1 microgram/40 microliters of particle suspension) was added to the suspension during gentle vortexing. After a 20 minute incubation at room temperature, the particle complexes were added to the cultures with swirling to distribute the particles evenly. RAW264.7 monocyte/macrophage lineage cells were grown to confluence in 24 well plates were washed with PBS, and then incubated for 24h with the MAA suspension in RPMI containing 10% FCS. Cells in which GFP has been expressed from the pEGFP plasmid were examined by UV microscopy at appropriate time points after culture initiation (usually 24h), and photographed under both visible light and UV illumination conditions as shown in Figure 2A and Figure 2B. Approximately 25% of the treated cells showed high level GFP expression.

Example 5

Comparison of Transfection Efficiency MAA-PEI and Lipofectin in Serum and Serum Free Medium

[0124] To determine the efficiency of *in vitro* transfection in the presence or absence of serum in the medium, cells were transfected with a DNA conjugated to MAA-PEI or Lipofectin. Similar protocols were followed as in Example 4; however, a monocyte/macrophage lineage murine cell line (RAW) was transfected with a luciferase construct under cytomegalovirus (CMV) promoter regulation conjugated to MAA-PEI and was compared to plasmid/Lipofectin conjugates. In this experiment, the efficiency of transfection in the presence of 10% fetal calf serum (FCS) supplemented culture medium was tested. The positive control was transfection with lipofectin + 1 μg of plasmid in serum free medium. Negative controls included untreated cells, cells exposed to plasmid alone, and cells exposed to MAA-PEI alone. Test cultures were exposed to a concentration curve of plasmid + MAA-PEI, from a maximum of 2 μg to a minimum of 0.25 μg of plasmid. The full curve was done under identical conditions to the positive control, and two concentration points were done in which the cells were exposed in the presence of 10% fetal calf serum.

[0125] The results are expressed in lumens, and represent 4/100 of the total culture cell extract from 1ml culture in a 24 well plate. Figure 3 is a bar graph representation of the data illustrated below in Table 1.

TABLE 1

SERUM FREE MEDIUM	LUMENS
Untreated cells	0.00
Plasmid alone	0.00
MAA-PEI alone	0.00
Lipofectin + 1 μg Plasmid	551.0
MAA-PEI + 2 μg Plasmid	711.0
MAA-PEI + 1 μg Plasmid	336.0
MAA-PEI + 0.5 μg Plasmid	57.5
MAA-PEI + 0.25 μg Plasmid	5.7
IN 10% SERUM MEDIUM	**IN 10% SERUM MEDIUM**
MAA-PEI + 1 μg Plasmid	1029.0
MAA-PEI + 0.25 μg Plasmid	76.3

[0126] This data illustrated that the MAA-PEI bound plasmids were as efficient as Lipofectin (one of the most widely used agents for serum free transfections). Furthermore, the data illustrated that the MAA-PEI conjugates were equally or more efficient in the presence of serum. Most agents are inefficient *in vivo* because of the presence of serum proteins. Therefore, a skilled artisan realizes the enormous implications of this data and its use for *in vivo* DNA trasfection strategies.

Example 6

Humoral Immune Responses Elicited by Intravenously Injected MAA-PEI Bound Plasmid

[0127] To evaluate immune responses to antigens expressed in the lung tissue, mice were injected intravenously with 5 μg of pCMV-hGH (SEQ.ID.NO:13) loaded on MAA-PEI particles, or intravenously with 50 μg of pCMV-hGH. At biweekly intervals, serum was collected from each mouse via tail bleed. At the end of the experiment, the mice were sacrificed and bronchoalveolar lavage was performed to evaluate antibody responses in pulmonary secretions.

[0128] Controls included uninjected animals and animals in which naked hGH plasmid were injected intramuscularly. Figure 4A illustrates the total systemic antibody response to hGH elicited by the MAA-PEI plasmid through 12 weeks in one group of mice, showing a rapid and strong response from the single dose of plasmid, which appeared to plateau after 4 weeks. Intramuscular injection of naked DNA showed essentially the same level of antibody response systemically, and the differences from uninjected control animals for both immunized groups were statistically significant at all time points ($p<0.02$ at all time points). Figure 4B shows a dilution curve of serum at 12 weeks illustrating that the antibody dilutes out to a titer of >1:32,000 in the MAA-PEI and

intramuscularly injected animals, with the optical density at each dilution being statistically different from controls ($p<0.01$). Figure 4C shows a second set of mice injected with MAA-PEI bound hGH plasmid and compared with other controls: the same quantity of hGH plasmid injected intravenously as naked DNA or as PEI-DNA complexes. MAA-PEI-hGH responses showed high titer systemic antibody, with somewhat higher levels than seen with naked DNA intravenously alone.

[0129] The isotype distribution of the humoral response at 8 weeks to MAA-PEI-hGH plasmid injection group is shown in Figure 5A, along with intramuscularly hGH and naive control groups, demonstrating strong IgM and total IgG response, which was dominantly IgG1, with modest IgG2a and little IgG2b or IgG3. This isotype distribution was also essentially the same at 2, 4, and 12 weeks (Figure 5B).

[0130] Mucosal antibody responses are shown in Figure 6A, demonstrating that high titer IgA anti-hGH antibody is present in the lung secretions of only MAA-PEI-hGH plasmid immunized mice. Figure 6B shows the composite data from 2 experiments comparing particle-mediated immunization with different controls. Although a substantial systemic response was present from immunization with naked DNA administered intravenously or intramuscularly (Figures 4B and 4C), no significant quantity of specific IgA or IgG antibody was present in either group in lung secretions (Figure 6B). The quantity of IgA measured in the bronchoalveolar lavage fluids of the particle-immunized group was significantly different from the levels of IgA in the other groups ($p<0.01$), as well as from those for IgG in its own bronchoalveolar lavage fluids and that of all other groups ($p<0.01$).

[0131] Therefore, a skilled artisan recognizes that intravenous injection of conjugated plasmid to MAA-PEI elicited an equal or a stronger immune response compared to intramuscular injection of plasmid DNA alone. Furthermore, only the MAA-PEI plasmid induced a mucosal response suggesting that this delivery system (MAA-PEI) via a systemic route induces a mucosal response, which is not typical of systemic immunizations.

EXAMPLE 7

Oral administration of Particle Bound hGH Plasmid and Syrijet Injection Elicit Mucosal Antibody

[0132] Mice were orally immunized with 15 μg of pCMV-hGH (SEQ.ID.NO:13) plasmid in single doses, and controls included mice orally exposed to 15 μg of pCMV-hGH plasmid alone (naked DNA), 15 μg of pCMV-hGH plasmid complexed with MAA-PEI, and PBS alone. As shown in the Figure 8, particle immunized mice developed

specific vaginal IgA antibody, while controls failed to develop significant antibody responses.

[0133] Mice were also immunized with a jet injection device (Syrijet, Inc., Cherry Hill, NJ). Mice were injected with 30 μg of pCMV-hGH in 15 μL of PBS in the buccal tissue or the perineal tissue. After 4 weeks, vaginal secretions were collected by the wick method and pooled secretions were assayed at 1:2 for IgA and IgG. Comparable levels of anti-hGH IgA were present in vaginal secretions in the Syrijet immunized mice. The particle group secretions were positive to >1:16 dilution, while the Syrijet group secretions were positive to 1:8.

[0134] Groups of five mice were injected with 30 μg of pCMV-hGH in 15 μL of PBS in the buccal tissue or the perineal tissue, or orally treated with 15 μg plasmid bound to MAA-PEI particles, 15 μg complexed with free PEI, or 15 μg naked DNA. Vaginal secretions were collected by the wick method 4 weeks later, and pooled secretions were assayed at 1:2 for IgA and IgG.

[0135] Therefore, the data suggested that oral administration of MAA-PEI particles elicited a stronger immune response than particles administered via a Syrijet or bound to only a polycationic polymer.

EXAMPLE 8

Construction of an Expression Library Immunization

[0136] There were several reasons why it was thought that this approach might be effective. First, the library would theoretically express all of the pathogen antigens and might therefore promote broader, better protection, since epitopes are presented independently. Second, the libraries truncate each protein rendering it inactive and reducing its potential toxicity to mammalian cells. Third, to better "reveal" the pathogen to the immune system, each fragment in two of the libraries was fused to heterologous mammalian sequences to "target" the antigens within the mammalian cells (Figure 9). Breaking down the proteins and fusing them to heterologous sequences appears to elicit potent immune responses. For example, fusion of a 602 base pair fragment of gp120 to ubiquitin produces CTL responses in mice when the plasmid (UB#23) is used for immunization with particles (Figure 7A and 7B).

[0137] Immunization libraries were constructed by creating overlapping PCR fragments (400-600 bp) from each open reading frame in the HIV genome (Wang *et al.*, 1993) (Figure 9). These fragments were then inserted into pCMV expression vectors as shown, with fusion to ubiquitin or hGH coding sequences, or without fusion to another expressed sequence. The carboxy terminus of ubiquitin directs the fusion product to the proteasome, where it is degraded to peptides which are presented on MHC class I

molecules. Fusion to hGH results in secretion of the fused product directing the antigen to be presented on MHC class II molecules.

[0138] Furthermore, a skilled artisan realizes that the ELIs can be constructed using either genomic DNA or cDNA (Manoutcharian, 1998). Therefore, the utilization of this technology, and variations thereof, such as those described by U.S. Patent No. 5,989,553 and 5,703,057, each incorporated herein by reference, are exemplary methods of construction of ELIs and their use in DNA vaccines.

EXAMPLE 9

Enzyme Linked Immunosorbent Assay (ELISA)

[0139] Serum, vaginal secretions, and intestinal secretions were assayed by ELISA for total and isotype specific antibody to HIV antigens (purified HIV proteins are obtained from ABI, Columbia, MD). The desired antigen was coated onto microtiter plates (Immunlon II, Dynex Technologies, Chantilly, VA) at 0.5 μg/mL (50 ng/well) in PBS buffer (pH 7.3) overnight at 4°C. This loading quantity was the most cost effective, shown by comparison of various concentrations with serial dilutions of a positive control antiserum. The wells were then blocked with 5% non-fat milk in PBS. Sera and mucosal secretions were diluted in PBS and aliquots added to the wells were incubated overnight at 4°C. Sera and secretions from age matched, unimmunized Balb/C mice served as negative controls in each assay. After 5 washes with PBS-Tween (0.1%), bound antibodies were detected with horseradish peroxidase-conjugated goat or rabbit anti mouse immunoglobulin (Bio-Rad, Hercules, CA), or anti-mouse IgA, IgM (Sigma), IgG1, IgG2a, or IgG2b (Serotec, Raleigh, NC) diluted in PBS-Tween. Reactions were developed using TMB substrate (Calbiochem) and the optical density was measured at 405 nm with an SLT microplate reader (TELAC Inc., Research Triangle Park, NC) with a maximal O.D. for linear reading of 1.4, with the background reagent only (no serum) well having an O.D. of 0.1. Results of the isotype specific assays were normalized for equivalent signal strength from dilution curves of bound antigen for each isotype.

EXAMPLE 10

Cytotoxicity Assay

[0140] Mice were exposed to plasmid encoded antigens using particles or jet injections. Single cell suspensions were prepared from mouse spleen or mucosal tissues as described in Example 1. For pCMV-UB-#23 (SEQ.ID.NO:1) immunized animals, P815 target cells were loaded with the desired peptide, *e.g.*, p18 (RIQRGPGRAFVTIGK) (SEQ.ID.NO:9), by incubation at 37°C for 1h at 1 μM. Splenocytes (variable numbers) and targets (10,000 cells/well) were co-cultured at desired effector/target ratios, and control cultures included splenocytes with target cells loaded with irrelevant peptide or no

peptide. Maximum release was determined by lysing target cells alone, and spontaneous release from both target cells and effector cells was measured from other wells with these cells cultured individually. After a 4h incubation, supernatant aliquots were harvested, substrate was added for LDH activity released by lysed cells, and optical density measurements were made after 30 minutes (Cytotox96 Assay, Promega).

Example 11

MAA-PEI Bound HIV Plasmid Elicits CTL in Spleen and Gut

[0141] Mice were immunized as described in Example 6, except a plasmid from the HIV-library constructed with ubiquitin to enhance CTL induction (Wu *et al.*, 1997; Fu et al, 1998) was used. The plasmid (CMV-UB-#23, (SEQ.ID.NO:1)) encodes a protein containing ubiquitin fused to a protein fragment containing the immunodominant epitope for gp120 in Balb/C mice, p18 (Takahashi *et al.*, 1988) and conjugated to MAA-PEI as shown in Example 2. Eight weeks after vaccination, the spleens and intestines were harvested, the tissues minced through a fine screen (intestinal tissue was also briefly incubated with collagenase), and the mononuclear cells collected by density gradient centrifugation. These cells were assayed directly for CTL activity with various effector:target (E:T) ratios. As shown in Figure 7A, cytolytic T cells were present in splenocytes of the UB#23 immunized mice, and there was no nonspecific lytic activity toward the target cells without peptide loading. The lytic activity at E:T ratios of 25:1, 12.5:1 and 6.25:1 were significantly different from the control wells containing an E:T ratio of 25:1 using target cells not loaded with peptide ($p<0.01$ for each). Figure 7B shows intestinal epithelial lymphocytes (IELs) tested in a similar manner. Lytic activity was significant in the IELs with 37% target cell lysis at a 50:1 E:T ratio.

EXAMPLE 12

CTL Responses to Oral Administration of Particle Bound Plasmid

[0142] Groups of mice were orally immunized with MAA-PEI bound UB#23 (SEQ.ID.NO:1), a plasmid encoding a 450 base pair region of the HIV-1 gp120 gene containing the V3 loop with both antibody epitopes and the 15mer amino acid sequence (p18) that is the strong immunodominant CTL envelope epitope in H-2d mice (Takahashi *et al.*, 1988). This plasmid is one member of the HIV-1 library constructed with the viral sequence fragment fused to the carboxy terminus of ubiquitin (thus directing the fusion product to the proteasome, where it is degraded to peptides which are then presented on MHC class I molecules (Michalek *et al.*, 1993). Mice were given an oral booster dose at 6 weeks and then the mice were sacrificed at 8 weeks for CTL assays. Total gut mononuclear cells were harvested by mincing the tissue, briefly digesting with collagenase, and subjecting the cells to density gradient centrifugation. Total intestinal mononuclear cells were chosen because the yield from the intestine is sufficient to permit

full assays to be performed with a limited number of animals pooled. Direct CTL assays on these cells (*i.e.*, assays done with the fresh cells and no prestimulation) and on splenocytes were performed with p18 loaded P815 target cells or control cells without peptide loading.

[0143] Figure 10A shows high level spleen cytotoxic activity present at the time of sacrifice with 52% lysis of the target cells after 4h of incubation at a 25:1 E:T ratio. In the intestinal mononuclear cell population, substantial lytic activity was also present (Figure 10B) with 37% target cell lysis at a 50:1 E:T ratio. Lysis was specific, since no lytic activity was found in cultures of the mononuclear cell population and P815 cells that were not loaded with the p18 peptide. Hence, this experiment demonstrates that oral immunization is capable of eliciting the accumulation of active cytotoxic effector cells in the gut tissue.

EXAMPLE 13

Evaluation of CTL in Genital Tissue

[0144] Cytolytic activity in mononuclear cells isolated from the vagina and cervical tissues was detected in immunized mice.

[0145] Briefly, five mice were injected intradermally in the perineal skin with 25 μg UB23 plasmid (SEQ.ID.NO:1) in 25 μL PBS, and then boosted with the same dose 4 weeks later. Tissues were harvested and pooled from all the mice at 8 weeks and a single cell mononuclear cell preparation was assayed for cytolytic activity against p18 loaded target cells. Control cultures at a 25:1 E:T ratio contained tissue cells co-cultured with target cells not loaded with peptide.

[0146] As shown in Figure 11, mice that were immunized and boosted with the single plasmid have active CTL in freshly isolated total mononuclear cells from genital tissues and the spleen. The genital cells preparation contained slightly higher levels of nonspecific lytic activity (7%) that has been seen with other samples, but the lysis of p18 peptide loaded cells was substantially higher (37%). This experiment demonstrates that lytic activity is elicited by genetic immunization.

EXAMPLE 14

Humoral Immune Responses Elicited By Intravenously Injected MAA-PEI Bound Plasmid In Macaques

[0147] Six female macaques were immunized by intravenous injection of particle bound plasmids. A library of SHIV antigens fused to ubiquitin were used with the intent of maximizing T cell responses.

[0148] The cloned HIV-1_{IIIB} (SEQ.ID.NO:4) isolate were used to construct expression libraries for each open reading frame with sequence fragments of 400-600 bp. Plasmids were constructed with each viral sequence fragment fused to the carboxy terminus of ubiquitin. Control plasmids were the backbone plasmid used in construction of the library but without coding sequence inserts.

[0149] The monkeys were immunized intradermally with 160 μg of plasmid (equal quantities of each of the 32 different plasmids bound to MAA-PEI (containing 500 μg of HSA and 215 μg of PEI)). After immunization of the monkeys, sera and secretions (vaginal, oral, and endobronchial) were collected at intervals and assayed for antibody responses to HIV antigens, including envelope (using gp160), p24, and p66 (reverse transcriptase).

[0150] As shown in Figure 12A, a significant serum antibody response to p24 was present after a single injection in all six monkeys, with an average titer of 1:3000. Anti-p24 IgA antibody was demonstrable in oral, endobronchial, and, most importantly, in vaginal secretions. In vaginal secretions, the anti-p24 IgA titer was estimated to be at least 1:32. In addition, 6/6 had a similar response to envelope and 3/6 had a response to p66 in both serum and vaginal secretions after the first injection.

[0151] Samples collected at 12 weeks (3 weeks after boosting IV with the same MAA-PEI-plasmid dose, Figure 12B) showed an increase in anti-p24 antibody in serum in 5/6 monkeys with an average titer of 1:6800 in serum, and 1:128 in vaginal secretions. All the boosted monkeys showed a response to gp160 of 1:1000 or greater in serum and 1:32 or greater in vaginal secretions (anti-p66 assays were not performed). Similar responses were also found in oral and endobronchial secretion samples. Therefore both systemic and mucosal antibody responses were elicited to particle bound library plasmids with a prime and single boost regimen.

Example 15

T cell responses elicited by intravenously injected MAA-PEI bound plasmid in macaques

[0152] To assess T cell responses in this pilot experiment, the proliferative and cytokine production of peripheral blood cells to stimulation *in vitro* with HIV antigens was examined.

[0153] Six macaques were immunized at week 0 and boosted at week 9. Peripheral mononuclear blood cells (PBMCs) were isolated and stimulated *in vitro* with selected peptides and assayed to IFNγ production and T cell proliferative responses.

[0154] ELISPOT assay for single cells with IFN-γ release was used as a measure of T cell responses. This assay is known to correlate closely with CTL responses assessed by limiting dilution cytotoxicity assays and MHC tetramer-peptide binding (Tan *et al.*, 1999), thus one skilled in the art recognizes that this represents a technique to evaluate multiple T cell epitope responses .

[0155] Briefly, the ELISPOT assay is used for both detection and quantitation of cytokine-secreting cells in response to antigen. $CD4^+$ and $CD8^+$ T cell populations are separated from freshly isolated PBMCs by a magnetic bead procedure and then stimulated in duplicate wells of 96 well plates (polyvinylidene difluoride backed plates, MAIP S 45, Millipore, Bedford, MA). The wells are precoated with anti-IFNγantibody (5 μg/mL) in 0.1 M bicarbonate buffer (pH 9.6) by overnight incubation at 4°C. Subsequently, the plates are washed 4 times with PBS, and serial dilutions of the cells, in complete RPMI 1640 medium, are mixed with stimulator cells and added to duplicate wells. The stimulator cells are either autologous PBMC or dendritic cells infected with recombinant vaccinia virus expressing HIV antigens, and fixed with 1% paraformaldehyde. After incubation for 40h at 37°C the cells are removed, and the wells are thoroughly washed with PBS and incubated with 100 μL of biotynylated second IFNγ antibody (detection antibody) for 3 h at 37°C. Avidin peroxidase is added and incubated for another 30 minutes. Spots representing IFNγ -secreting cells are developed using freshly prepared substrate (0.3 mg/mL of 3-amino-9-ethyl-carbazole) in 0.1 M sodium acetate buffer, containing 0.015% hydrogen peroxide. Plates are washed to stop color development, and spots are counted using a dissecting microscope. Only spots with fuzzy borders and diffused are scored as positive.

[0156] As shown in Figure 13, half of the monkeys responded to some T cell epitopes by 4 weeks after the first immunization, and all the monkeys responded after the booster immunization. Responses to several different peptides were detectable after the priming dose, but boosting recruited many other responses that were initially below the level of detection.

[0157] After boosting, 5/6 monkeys demonstrated T cell proliferative responses to multiple peptides, and 4/6 released IFNγ after stimulation with one or more peptides.

[0158] Figure 14 shows the distribution of proliferative responses by the individual monkeys to specific peptides. Briefly, the isolated PBMCs were stimulated with the indicated HIV-1 envelope peptides, intact HIV-1 p24 or p66 protein, or with heat inactivated SHIV and proliferation was assayed by ^3H thymidine uptake.

$$\text{Stimulation index} = \frac{\text{antigen-stimulated } ^3H \text{ uptake}}{\text{media-stimulated } ^3H \text{ uptake}}$$

EXAMPLE 16

Evaluation of Humoral and Cellular Responses to Oral Administration

[0159] Monkeys are orally immunized similar methods described herein. Of note is that for the orally immunized monkeys, gastric acidity is suppressed by prior administration of omeprazole (a proton pump inhibitor). One skilled in the art recognizes that this may not be essential since the vaccine is a suspension of the particle bound plasmids. Yet further, it is contemplated that the particles can be dried and incorporated into food or capsules. By selection of appropriate encapsulation materials, the gastric environment can be bypassed.

[0160] The immunological monitoring is necessarily limited by the quantity of blood that can be collected in these animals. Humoral immunity is assessed using the ELISPOT assay for IFNγ release as the principal measure of T cell responses.

[0161] After a booster regime, the monkeys are challenged by intravaginal administration of $SHIV_{ku-2}$ (SEQ.ID.NO:3). The intravaginal challenge is with a total volume of 1 mL $SHIV_{ku2}$ (10^4 $TCID_{50}$) from a needle-less syringe followed by gentle spread of the inoculum with the plunger of a 1 mL syringe. Virus infection in the animals is ascertained by monitoring virus load in the plasma as well as PBMCs. After challenge, the monkeys are closely followed clinically by the veterinarians responsible for their care, so that the clinical course of illness in infected monkeys is thoroughly documented, in addition to the assessment of the virologic assays. For viral load determination, quantitative competitive PCR is used. Other methods can be used to determine viral load included, but not limited to real time QC RT-PCR.

[0162] From this data, one skilled in the art recognizes that the present invention provides a new vaccine for autoimmune deficiency syndrome (AIDS).

EXAMPLE 17

Evaluation of the Humoral and Cellular Immune Response to Plasmids of Three Different Modes of Expression Using Oral and Jet Injection Routes of Administration

[0163] To determine whether oral administration of particle bound DNA elicits mucosal humoral and cellular immune responses equivalent or better than jet injection of naked DNA, animals are immunized with an expression vector containing the HIV gp120 protein fragment (the plasmid consists of a 450 base pair region containing the V3 loop with both antibody epitopes and the 15mer amino acid sequence (p18) that is the strong immunodominant CTL envelope epitope in H-2^d mice (Takahashi *et al.*, 1988)). The p18

epitope is also recognized by $H2^b$ and a number of other murine haplotypes (Shirai *et al.*, 1997). Antibody responses to gp120 are well characterized in mice, and therefore plasmids expressing this protein are valuable tools for evaluating genetic immunization responses to the different administration conditions. Vectors are used expressing the protein fragment alone (unfused, for natural expression dependent on the properties of the native amino acid sequence) or vectors that have been designed specifically for induction of either antibody or cytolytic T cells (Sykes et al, 1999). In the latter plasmids, the gp120 fragment is fused to either the carboxy terminus of ubiquitin (thus directing the fusion product to the proteasome, where it is degraded to peptides which are then presented on MHC class I molecules (Michalek et al, 1993)), or to human growth hormone (for secretion of the fused product and presentation on MHC class II molecules and B lymphocytes; the hGH also provides a separate positive control for immunization in mice). All plasmids are conjugated to MAA-PEI as shown in Example 2.

[0164] Mice are immunized with a dose range of particle preparations (1 pg to 50 µg, since gp120 expression levels will not necessarily be identical with those of the hGH reporter plasmid), and assays for systemic and mucosal humoral immune responses by isotype specific ELISA (Haneberg *et al.*, 1994) are performed at intervals (4, 8, and 12 weeks). Assays for cytotoxic T lymphocytes in spleen cells and mucosal lymphocytes isolated from intestinal tissue, genital organs, and pelvic lymph nodes are performed at 4, 8, and 12 weeks on separate groups of animals using p18 loaded target cells in a standard CTL assays. For each group, blood and vaginal secretions are collected at 4 and 8 weeks, and intestinal secretions are collected at 12 weeks for humoral response evaluation similar to Examples 6 and 9.

EXAMPLE 18

Enhancement of Single Plasmid Oral Immunizations

[0165] To determine the enhancement of a booster regimen, mice were orally immunized with the UB#23 plasmid (SEQ.ID.NO: 1) bound to MAA-PEI. Assays of CTLs showed cytotoxicity of 17% for p18 loaded P815 target cells at a ratio of 50:1 at 8 weeks. An oral booster dose was followed by an assay 10 days later and showed an increase in lytic activity to 43% at the 50:1 E:T ratio. Hence, CTLs are elicited by oral immunization, and optimization of the vaccination conditions with boosting or other enhancements (*i.e.*, co-administration with a cytokine) will substantially improve the activity level.

[0166] To determine the enhancement of co-administration with cytokine expression vectors, immunizations are performed using methods similar to Example 17 . Mice are immunized with the gp120 vector and a cytokine expression vector. Assays are performed for each group to determine the humoral and cellular immune responses.

Blood and vaginal secretions are collected at 4, 8 and 12 weeks, and intestinal secretions are collected at 8 weeks for humoral response evaluation similar to the above Example 17. CTL responses are evaluated in spleen cells, and in mucosal lymphocytes isolated from genital and intestinal tissues collected at 4, 8 and 12 weeks.

[0100] Furthermore, a dose response experiment for intradermal injection of luciferase plasmid showed that low dose (10 ng) priming followed by a high dose plasmid booster (50 μg), resulted in a higher response than with any other combination. Therefore, a skilled artisan recognizes that these issues will need to be established for oral administration and jet injection. Possible experiments include but are not limited to, low, medium or high dose priming and single high dose booster at 4 weeks with assays done at 4, 8 and 12 weeks for humoral responses, and at 12 weeks for cellular responses.

EXAMPLE 19

Dosage Determination for Oral or Jet Injected Immunizations with ELIs Eliciting an Immune Response Similar to Single Plasmid Administration

[0168] To evaluate the possibility that co-administration of multiple plasmids (immunization with libraries containing multiple plasmids, not a single plasmid) may interfere with eliciting immune responses to an individual epitope, expression libraries were constructed as in Example 8. It has been observed that immunization with complex protein mixtures (Maceda *et al.*, 1985, Hammerl *et al.*, 1988) interferes with the elicitation of immune responses. Furthermore, immunizations with ELIs have only been delivered via a gene gun or intramuscularly or subcutaneous. Therefore, a skilled artisan realizes the necessity of determining the effective dose for an expression library to elicit the maximum immune response, especially the dose to be delivered orally.

[0169] The plasmid dose required to elicit equivalent immune responses to single plasmid administration was determined from the above examples, from gene gun and intramuscular studies (Barry *et al.*, 1997) and from intradermal injection studies with reporter genes showing that low doses of plasmid (approximately 100 ng) can produce equivalent responses if injected with a sufficient amount of noncoding vector. The additional noncoding plasmid was required both for protection of the plasmid from too rapid enzymatic breakdown and for the immune response enhancement of the local Th1 cytokine inducing effects of the CpG sequences in plasmid DNA.

[0170] Mice are immunized with a dose range of particle preparations (25μg to 100 μg) prepared similar to Example 8 and bound to MAA-PEI. Assays for systemic and mucosal humoral immune responses are measured by isotype specific ELISA (Haneberg *et al.*, 1994) are performed at intervals (4, 8, and 12 weeks). Assays for cytotoxic T lymphocytes in spleen and IEL from the gut, genital organs, and pelvic lymph nodes are

performed at 4, 8, and 12 weeks on separate groups of animals using p18 loaded target cells in a standard CTL assays.

[0171] With these results, the effects of boosting and cytokine enhancing plasmid administration under optimal conditions are evaluated. Assays are performed at 8 and 12 weeks on boost/cytokine treated groups of mice.

[0172] Furthermore, a skilled artisan recognizes that immunizations using ELIs are not limited to injecting only one library. Mixtures of libraries can be injected. For example, if 5 libraries were constructed from a particular genome of a parasite, then equal mixtures of the 5 individual libraries can be used for immunization studies. In addition, if one particular library is found to elicit a strong immune response, then sublibraries (libraries containing fewer clones) can be developed to enrich the library resulting in possibly a more potent vaccine (Piedrafita, 1999).

EXAMPLE 20

Immune Responses in Additional Mouse Strains

[0173] To ensure that the murine immune responses are not restricted to a single mouse strain, two additional mouse strains are studied. C57BL/6 mice ($H2^b$) produce CTL responses to the same HIV-1 V3 loop epitope (p18) (Shirai *et al.,* 1997), as well as making antibodies to this region of the envelope protein (Staats *et al.,* 1996). Hence, the same #23 plasmids from Example 8 was used to examine immune responses in this strain. CD-1 mice, a strain that is outbred and thus more analogous to human MHC variation, was also tested. This mouse has not been studied in terms of its actual histocompatibility types (according to Harlan-Sprague-Dawley, the source for these mice).

EXAMPLE 21

Evaluation of Immune Response in Regional Lymph Nodes

[0174] Regional lymph nodes cells with and without perineal boosting with the DNA expression vectors are examined. Although lymph nodes would not be the most optimal location to prove mucosal activity, the association of mucosal effector cells and regional node effector cells is well appreciated (Klavinskis *et al.,* 1996), and furthermore, the first locations beyond the mucosa for HIV replication are the local and regional lymph nodes. The pelvic nodes in two orally immunized mice were pooled. CTL activity was demonstrated 8 weeks after a single oral immunization in both a direct assay (13% at a 50:1 E:T ratio) and in an *in vitro* restimulation assay (28%, 50:1 E:T ratio).

EXAMPLE 22

Antigen Binding using Tetramer/Peptide Complexes

[0175] Genital tissue T cells are examined for antigen binding using soluble tetramer/peptide complexes to detect display of antigen specific receptors. This technology is well established in the art (Dunbar *et al.*, 1998, Gillanders *et al.*, 1997, Kuroda et al, 1999, Lefrancois, *et al.*, 1999 and Murali-Krishana, et al. 1998). Tetrameric peptide-MHC class I complexes are prepared by combining the recombinant fusion protein ß2-microblobulin-MHC class I extracellular heavy chain and the desired peptide under denaturing conditions in urea. Dilution of the denaturing conditions permits refolding of the monomeric class I complex around the peptide which is then biotinylated, chromatographically purified. Tetramers of the complex are formed by addition of fluorescein labelled avidin. Peptide specific CTL are identified by incubation of the complexes with cells at 37°C with or without labelled antibody to other cell surface antigens, washed, and analyzyed by flow cytometry.

[0176] A skilled artisan realizes that this strategy can be applied to any antigen to determine the antibody response in genital tissue after immunization.

Example 23

HSA/PEI Combination for Gene Expression

[0177] For preparation of plasmids for delivery by soluble protein and polyethylenimine, human serum albumin (HSA) (or other proteins) was mixed in PBS to the desired stock concentration with polyethyleneimine (PEI (750 kD), suspended in PBS, and pH adjusted to 7.4, in a mole ratio between approximately 1.5:1 and 150:1 (usually 15:1). For plasmid binding, the HSA/PEI stock solution is diluted in PBS to the desired volume for combination with the plasmid at an N:P ratio between 10:1 and 20:1 (usually 15:1), and the plasmid (diluted in PBS to 200 ng/μL) was added dropwise with gentle vortexing of the solution. The solution was then incubated at room temperature (RT) for 20 minutes before administration.

[0178] Mice were injected intravenously with pCMV-Luc bound HSA/PEI (non-conjugated), and then were sacrificed at 24h for luciferase assay of the lungs. In these experiments, all conditions tested were compared with the standard condition of 1 μg of DNA combined the HSA/PEI at an N:P ratio of 15:1, expressed as a 100% response. The albumin content of each preparation was at a molar ratio of 15 HSA to 1 PEI. In Figure 15A illustrates a dose response curve for the quantity of DNA injected (each condition in a consistent volume of 200 μL). This demonstrated that the maximal response was achieved near 1 μg of plasmid injected under these conditions. In Figure 15B, 1 μg was injected in each animal with a range of N:P ratios. Ratios between 1:10 and 1:20 showed

good transfection, and in this experiment, 1:12 showed a slightly higher level of transfection than 1:15. In parallel experiments, pCMV-Luc bound to PEI over a range of N:P ratios in the absence of added HSA showed luciferase activity <<1% of that achieved with standard HSA/PEI conditions.

[0179] Thus, the present invention provides a new gene delivery system, HSA/PEI, that does not have to be conjugated.

Example 24

Kinetics of Gene Expression and Repeated injections

[0180] Mice were injected with 1 μg pCMV-Luc and HSA/PEI at an N:P ratio of 1:15, and then assayed for luciferase activity in ng of enzyme per whole lung preparation. After a single injection, Figure 16A shows that gene expression is maximal at 24h and 48h, but has a marked decline at 72h and thereafter.

[0181] In Figure 16B, mice were injected with the same preparation as in Figure 16A either one, two or three times at spaced intervals over 48h, and then assayed for luciferase activity.

Example 25

Effects of Different Proteins and Concentrations of Proteins on PEI Based Gene Delivery

[0182] Mice were injected with 1 μg of pCMV-Luc bound to PEI (N:P of 15) in the presence of different concentrations of HSA (Figure 17A) or different proteins (Figure 17B), and then assayed for luciferase activity at 48h.

[0183] In these experiments, the luciferase activity was expressed as the percentage of the maximal response obtained under the standard conditions of an HSA:PEI molar ratio of 15. Figure 17A shows that there is a broad range of tolerance for protein quantities between a molar ratio of 1.5 to 150, while Figure 17B shows that other soluble proteins can also be used to enhance gene delivery by PEI *in vivo*.

Example 26

Organ Distribution Studies

[0184] Gene expression using the luciferase expression vector pCMV-Luc was examined comparing IV injection of HSA/PEI bound plasmid with MAA-PEI bound plasmid.

[0185] Mice were injected with 1 μg of plasmid bound at a 15:1 N:P ratio to the PEI present in either preparation, and then they were sacrificed at 48h and the organs harvested. Equivalent weight samples (whole lung in these mice was an average of 70 mg

in mass) for each organ were harvested and assayed for luciferase activity, with gene activity expressed in luciferase enzyme/mg of tissue (Figure 18A and Figure 18B). Although none of the other organs had high levels of activity, the organs with HSA/PEI showed that roughly 2-3% of luciferase activity may be distributed outside the lung. With MAA-PEI, in contrast, the luciferase activity outside the lung is <<1% of the total.

[0186] Thus, the present invention provides a new gene delivery system for lung tissue using non-conjugated bound plasmids.

REFERENCES

[0187] All patents and publications mentioned in the specification are indicative of the level of those skilled in the art to which the inventions pertains. All publications are herein incorporated by reference to the same extent as if each individual publication was specifically and individually indicated to be incorporated by reference.

Allan *et al.*, 1995. J Acquir Immune Defic Syndr. 9:429-441

Altman *et al.*, 1996. Science. 274(5284):94-6

An *et al.*, 1997. J Virol. 71(3):2292-302.

Baba *et al.*, 1999. Nature Med. 5(2):194-203

Barry and Johnston. 1997. Vaccine. 15:788-791

Barry *et al.*, 1995. Nature. 377:632-635

Benson *et al.*, 1998. J Virol. 72:4170-4182

Bloom. 1996. A perspective on AIDS vaccines. Science. 272:1888-1890.

Boyer *et al.*, 1997. Nature Med. 3:526-532

Brayton *et al.*, 1998. Ann N Y Acad Sci. 849:369-371.

Bryson *et al.*, N Engl J Med. 332:833-838

Carson *et al.*, 1997. J Exp Med. 186:1621-1622

Chen *et al.*, 1998. J Immunol. 160:2425-2432

Chow *et al.*, 1998. J Immunol. 160:1320-1329

Chu *et al.*, 1997. J Exp Med. 186:1623-1631

Colombetti *et al.*, 1975. Internatl J Nuclear Med Biol. 2:180-184.

Czerkinsky *et al.*, 1999. Immunological Reviews 170:197-222

Daniel *et al.*, 1992. Science. 258:1938-1941

Doe *et al.*, 1996. Proc Natl Acad Sci (USA). 93:8578-8583

Dolin 1995. J Inf Dis. 172:1175-1183

Donnelly *et al.*, 1997. DNA Vaccines, p. 617-648. *In* W. E. Paul, C. G. Fathman, and H. Metzger (ed.), Annual Review of Immunology, vol. 15. Annual Reviews, Inc., Palo Alto, CA

Dunbar *et al.*, 1998. Curr Biol. 8(7):413-6

Fattom *et al.*, 1999. Vaccine. 17(2):126-33

Fu *et al.*, 1998. Vaccine. 16(18):1711-7

Fuller and Haynes 1994. AIDS Res Hum Retrovir. 10:1433-1441

Fynan *et al.*, 1993. Proc Natl Acad Sci (USA). 90:11478-11482

Gallichan and Rosenthal 1996. J Exp Med. 184(5):1879-1890

Gilkeson *et al.*, 1993.Clin Immunopathol. 68:283-292

Gilkeson *et al.*, 1996. J Exp Med. 183:1389-1397

Gillanders *et al.*, 1997. Int Immunol. 9(1):81-9

Grifantini *et al.*, 1998. Eur J Immunol. 28(4):1225-32

Hammerl *et al.*, 1988. Mol Immunol. 25(3):313-20

Haneberg *et al.*, 1994. Infect Immun. 62:15-23

Hartl *et al.*, 1999. J Allergy Clin Immunol. 103(1 Pt 1):107-13

Hasleton and Curry 1996. Anatomy of the lung, p. 1-55. In P. S. Hasleton (ed.), Spencer's Pathology of the Lung, Fifth ed. McGraw-Hill, New York.

Hu *et al.*, 1992. Science. 255:456-459

Huang *et al.*, 1994. Science. 264:961-965

Hunt *et al.*, 1995. Vaccine. 13(17):1649-57

Ishikawa *et al.*, 1977. Immunology. 32(5):755-66

Jenkins *et al.*, Davis SS. 1995. J Drug Targeting. 3:79-81.

Kawabata *et al.*, 1995. Pharm Res. 12:825-830.

Kim *et al.*, 1998. Eur J Immunol. 28:1089-1103

Kim *et al.*, 1997. Nature Biotechnol. 15:641-646

Klavinskis *et al.*, 1996. Journal of Immunology. 157(6):2521-7

Klavinskis *et al.*, 1997. Vaccine. 15(8):818-20

Klinman *et al.*, 1997. J Immunol. 158(8):3635-9

Kuroda *et al.*, 1999. J Virol. 73(2):1573-9

Lefrançois *et al.*, 1999. J Exp Med. 190(9):1275-1284

Lehner *et al.*, 1992. Science. 258:1365-1369

Lehner *et al.*, 1996. Nature Medicine. 2(7):767-75

Lew *et al.*, 1995. Hum Gene Ther. 6:553-564.

Livingston *et al.*, 1998. Infect Immun. 66(1):322-9

London and Rubin 1998. p. 643-653. *In* P. L. Ogra, J. Mestecky, M. E. Lamm, W. Strober, J. Bienenstock, and J. R. McGhee (ed.), Mucosal Immunology, 2nd ed. Academic Press, New York

Lu *et al.*, 1995. Virology. 209:147-154

Maceda Soares *et al.*, 1985. Int Arch Allergy Appl Immunol. 78(4):449-51

Mancini *et al.*, 1996. Proc. Nat. Acad. Sci. U.S.A. 93(22):12496-501

Manoutcharian *et al.*, Immunol Lett. 62(3):131-6

Marx *et al.*, 1993. Science. 260:1323-1327

Mathiowitz *et al.*, 1997. Nature. 386:410-414

Mattapallil *et al.*, 1998. J Virol. 72:6421-6429

Mazzoli *et al.*, 1997. Nature Med. 3:1250-1257

McMichael and Phillips 1997. Escape of human immunodeficiency virus from immune control, p. 271-296. *In* W. E. Paul, C. G. Fathman, and H. Metzger (ed.), Annual Review of Immunology, vol. 15. Annual Reviews, Inc., Palo Alto, CA

Mestecky *et al.*, 1994. AIDS Res Hum Retroviruses. 10S2:S11-S20

Michalek *et al.*, 1993. Nature. 363:552-555

Miller *et al.*, 1992. Lab Invest. 68:129-145

Mitchell *et al.*, 1995. Immunotechnology. 1:211-219.

Mowat 1987. Immunol Today. 8:93-98

Murali-Krishna *et al.*, 1998. Immunity. 8(2):177-87

Ogra *et al.*, 1968. N Engl J Med. 279:893-900

Oxford and Jeffs 1996. Vaccine. 14:1712-1717

Pantaleo *et al.*, 1995. N Engl J Med. 332:209-216

Piedrafita *et al.*, 1999. J Immunol. 163(3):1467-72

Roy *et al.*, 1999. Nat Med. 5(4):387-91

Schirmbeck *et al.*, 1995. J Virol. 69:5929-5934

Schmid *et al.*, 1994. Acta Gastroenterol. 32:665-670.

Shirai *et al.*, 1997. J Immunol. 158:3181-3188

Staats *et al.*, 1996. J Immunol. 157:462-472

Sykes and Johnston 1999. DNA Cell Biol. 18(7):521-31

Takahashi *et al.*, 1988. Proc Natl Acad Sci (USA). 85:3105-3109

Tan *et al.*, 1999. Human Gene Ther. 10:2153-2161

Tang *et al.*, 1992. Nature. 356:152-154.

Thierry *et al.*, 1997. Gene Ther. 4:226-237.

Thomson *et al.*, 1998. J Immunol. 160:1717-1723

Ulmer *et al.*, 1994. Vaccine. 12:1541-1544

Wang *et al.*, 1994. AIDS Res Human Retroviruses. 10:S35-S41

Wang *et al.*, 1993. Proc Natl Acad Sci (USA). 90:4156-4160

Weichselbaum and Kufe. 1997. Lancet. 349:SII 10-12.

Weiner *et al.*, 1997. Proc Natl Acad Sci U S A. 94(20):10833-7

Whelan *et al.*, 1999. J Immunol. 163(8):4342-8

Williams *et al.*, 1991. Proc Natl Acad Sci (USA). 88:2726-2730.

Wolff *et al.*, 1992. Hum Mol Genet. 1(6):363-9

Wu and Kipps. 1997. J Immunol. 159(12):6037-43

Zhu *et al.*, 1993. Science. 261:209-211.

[0188] One skilled in the art readily appreciates that the present invention is well adapted to carry out the objectives and obtain the ends and advantages mentioned as well as those inherent therein. Methods, procedures and techniques described herein are presently representative of the preferred embodiments and are intended to be exemplary and are not intended as limitations of the scope. Changes therein and other uses will occur to those skilled in the art which are encompassed within the spirit of the invention or defined by the scope of the pending claims.